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APPLICATION FOR UNITED STATES LETTERS PATENT

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TITLE: NEBULIZING CATHETER SYSTEM  
AND METHODS OF USE AND  
MANUFACTURE

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NEBULIZING CATHETER SYSTEM AND  
METHODS OF USE AND MANUFACTURE

1        REFERENCE TO RELATED APPLICATION

2                The present application incorporates by  
3        reference the copending application entitled "IMPROVED  
4        CATHETER SYSTEM FOR DELIVERY OF AEROSOLIZED MEDICINE FOR  
5        USE WITH PRESSURIZED PROPELLANT CANISTER" filed by the  
6        same inventor of the present application and on even date  
7        herewith.

8        BACKGROUND OF THE INVENTION

9                The present invention relates to aerosol  
10      delivery of medication to the lungs and more  
11      particularly, the present invention relates to delivery  
12      systems for application of nebulized medication to the  
13      lungs with improved delivery rates, efficiencies, and  
14      control.

15        Many types of medication can be administered to  
16      a patient via the respiratory tract. Medication  
17      delivered through the respiratory tract may be carried  
18      with a patient's inhalation breath as airborne particles  
19      (e.g. an aerosol or nebula) into the lungs where the  
20      medication can cross through the thin membrane of the  
21      alveoli and enter the patient's bloodstream. Delivery of  
22      medication via the respiratory tract may be preferred in  
23      many circumstances because medication delivered this way  
24      enters the bloodstream very rapidly. Delivery of  
25      medication to the lungs may also be preferred when the  
26      medication is used in a treatment of a disease or  
27      condition affecting the lungs in order to apply or target  
28      the medication as close as physically possible to the  
29      diseased area.

30        Although delivery of medication via the  
31      respiratory tract has been used for many years, there are  
32      difficulties associated with prior systems that have

1 limited their use and application. For example,  
2 conventional methods have provided for only limited  
3 medication delivery rates, efficiency, and control.  
4 Conventional methods for aerosol delivery result in a  
5 substantial portion of the medicine failing to be  
6 delivered to the lungs, and thereby possibly being  
7 wasted, or possibly being delivered to other parts of the  
8 body, e.g. the trachea.

9 Aerosols in general are relatively short-lived  
10 and can settle out into larger particles or droplets  
11 relatively quickly. Aerosols can also impact each other  
12 or other objects, settle out as sediment, diffuse, or  
13 coalesce. Aerosol particles can also be subject to  
14 hydroscopic growth as they travel. Delivery of medicine  
15 as airborne particles requires conversion of the  
16 medicine, which may be in liquid form, to an aerosol  
17 followed relatively quickly by application of the aerosol  
18 to the respiratory tract. One such device that has been  
19 utilized for this purpose is an inhaler. Inhalers may  
20 atomize a liquid to form an aerosol which a person  
21 inhales via the mouth or nose. Inhalers typically  
22 provide only limited delivery of medication to the lungs  
23 since most of the medication is deposited on the linings  
24 of the respiratory tract. It is estimated that as little  
25 as 10-15% of an aerosol inhaled in this way reaches the  
26 alveoli.

27 Aerosol delivery of a medication to a patient's  
28 respiratory tract also may be performed while the patient  
29 is intubated, i.e. when an endotracheal tube is  
30 positioned in the patient's trachea to assist in  
31 breathing. When an endotracheal tube is positioned in a  
32 patient, a proximal end of the endotracheal tube may be  
33 connected to a mechanical ventilator and the distal end  
34 is located in the trachea. An aerosol may be added to  
35 the airflow in the ventilator circuit of the endotracheal  
36 tube and carried by the patient's inhalation to the  
37 lungs. A significant amount of the aerosolized

1 medication may be deposited inside the endotracheal tube  
2 and the delivery rate of the medicine to the lungs also  
3 remains relatively low and unpredictable.

4 The low and unpredictable delivery rates of  
5 prior aerosol delivery systems have limited the types of  
6 medications that are delivered via the respiratory tract.  
7 For new medications that are relatively expensive, the  
8 amount of wasted medicine may be a significant cost  
9 factor in the price of the therapy. Therefore, it would  
10 be advantageous to increase the delivery rate or  
11 efficiency of a medicine delivered to the lungs.

12 Another consideration is that some aerosols  
13 delivered to the lungs may have adverse side effects,  
14 e.g. radioactive tracers used for lung scans. Therefore,  
15 it would be advantageous to minimize the overall amount  
16 of medication delivered while maintaining the efficacy of  
17 the medication by providing the same or a greater amount  
18 of the medication to the desired site in the respiratory  
19 tract.

20 Further, some medications may be more effective  
21 when delivered in certain particle sizes. Accordingly,  
22 an improved aerosol delivery system may provide for  
23 improved rates and efficiencies of delivery also taking  
24 into account the aerosol particle size.

25 It may also be important to administer certain  
26 medications in specific, controlled dosages. The prior  
27 methods of aerosol delivery not only were inefficient,  
28 but also did not provide a reliable means to control  
29 precisely the dosage being delivered.

30 It may also be advantageous to be able to  
31 target medication to a specific bronchus, or specific  
32 groups of bronchia, as desired, while avoiding delivery  
33 of medication to other portions of the lungs.

34 Taking into account these and other  
35 considerations, aerosol delivery via the respiratory  
36 tract could become an even more widely used and effective

1 means of medication delivery if the delivery rate and  
2 efficiency of the delivery could be improved.

3 SUMMARY OF THE INVENTION

4 According to an aspect of the present  
5 invention, there is provided a method and apparatus for  
6 delivering a drug with control and efficiency to a  
7 patient via the patient's respiratory system. A  
8 nebulization catheter is positioned in the patient's  
9 respiratory system so that a distal end of the  
10 nebulization catheter is in the respiratory system and a  
11 proximal end is outside the body. According to a first  
12 aspect, the nebulization catheter may be used in  
13 conjunction with an endotracheal tube and preferably is  
14 removable from the endotracheal tube. The nebulization  
15 catheter conveys medicine in liquid form to the distal  
16 end at which location the medicine is nebulized by a  
17 pressurized gas or other nebulizing agent. The nebulized  
18 medicine is conveyed to the patient's lungs by the  
19 patient's respiration which may be assisted by a  
20 ventilator. The nebulizing catheter incorporates  
21 alternative constructions taking into account anatomical  
22 considerations and the properties of the medicine being  
23 nebulized to provide delivery of medicine with control  
24 and efficiency.

25 BRIEF DESCRIPTION OF THE DRAWINGS

26 FIG. 1 shows an exploded view of a first  
27 embodiment of the present invention.

28 FIG. 2 shows an assembled view of the  
29 embodiment of FIG. 1.

30 FIG. 2A is a sectional view of the nebulization  
31 catheter of FIGS. 1 and 2.

32 FIG. 3 is a plan view of an alternative  
33 embodiment of the endotracheal tube shown in FIGS. 1 and  
34 2.

1           FIG. 4 is a cross sectional view taken along  
2       the line a-a' of the alternative embodiment of the  
3       endotracheal tube shown in FIG. 3 without the nebulizing  
4       catheter in place.

5           FIG. 5 is a cross sectional view taken along  
6       the line b-b' of the alternative embodiment of the  
7       endotracheal tube shown in FIG. 3 with the nebulizing  
8       catheter in place.

9           FIG. 6 is a plan view of an embodiment of the  
10      nebulizing catheter of FIGS. 1 and 2 shown in place in  
11      the trachea of a patient who is not intubated.

12          FIG. 7 is a view similar to that of FIG. 6  
13      showing an alternative embodiment of the nebulization  
14      catheter.

15          FIG. 8 is a cross section taken along lines  
16      a-a' of the nebulization catheter of FIG. 7.

17          FIG. 9 is a view similar to that of FIG. 7  
18      showing an alternative embodiment of the nebulizing  
19      catheter shown in FIG. 7.

20          FIG. 10 is a perspective view of a distal end  
21      of an alternative embodiment of the nebulization catheter  
22      shown in FIG. 1.

23          FIG. 11 is a perspective view of a distal end  
24      of an alternative embodiment of the nebulization catheter  
25      shown in FIG. 1.

26          FIG. 12 is a perspective view of an alternative  
27      embodiment of FIG. 11 with the liquid lumen shown in a  
28      closed condition.

29          FIG. 13 is a perspective view of the embodiment  
30      of FIG. 12 with the liquid lumen shown in an open  
31      condition.

32          FIG. 14 is a perspective view of a distal end  
33      of an alternative embodiment of the nebulization catheter  
34      shown in FIG. 1.

35          FIG. 15 is a perspective view of a distal end  
36      of an alternative embodiment of the nebulization catheter  
37      shown in FIG. 1.

1           FIG. 16 is a perspective view of a distal end  
2        of an alternative embodiment of the nebulization catheter  
3        shown in FIG. 1.

4           FIG. 17 is a perspective view of a distal end  
5        of an alternative embodiment of the nebulization catheter  
6        shown in FIG. 10.

7           FIG. 18 is a perspective view of a distal end  
8        of an alternative embodiment of the nebulization catheter  
9        shown in FIG. 1.

10          FIG. 19 is a sectional view of the distal end  
11        of the embodiment of the nebulization catheter shown in  
12        FIG. 18.

13          FIG. 20 is a sectional view of a distal end of  
14        an alternative embodiment of the nebulization catheter  
15        shown in FIG. 1.

16          FIG. 21 is a sectional view similar to that of  
17        FIG. 20 showing an alternative embodiment of the  
18        nebulization catheter shown in FIG. 20.

19          FIG. 22 is a perspective view partially in  
20        section of a distal end of an alternative embodiment of  
21        the nebulization catheter shown in FIG. 1.

22          FIG. 23 is a view similar to that of FIG. 22,  
23        showing an alternative embodiment of the nebulization  
24        catheter shown in FIG. 22.

25          FIG. 24 is a perspective view partially in  
26        section of a distal end of an alternative embodiment of  
27        the nebulization catheter shown in FIG. 1.

28          FIG. 25 is sectional view of a distal end of an  
29        alternative embodiment of the nebulization catheter shown  
30        in FIG. 25.

31          FIG. 26 is sectional view similar to that of  
32        FIG. 25 showing the embodiment of FIG. 25 during an  
33        exhalation stage of the patient.

34          FIG. 27 is a perspective view of alternative  
35        embodiments of the nebulization catheter and endotracheal  
36        tube shown in FIG. 1.

1           FIG. 28 is a perspective view of alternative  
2       embodiments of the nebulization catheter and endotracheal  
3       tube shown in FIG. 27.

4           FIG. 29 is a perspective view of an alternative  
5       embodiment of the nebulization catheter shown in FIGS. 27  
6       and 28.

7           FIG. 30 is a perspective view of the embodiment  
8       of the nebulization catheter shown in FIG. 29 shown with  
9       an endotracheal tube in a patient's trachea.

10          FIG. 31 is sectional view of a distal end and a  
11       diagrammatic view of a proximal end of an alternative  
12       embodiment of the nebulization catheter shown in FIG. 1.

13          FIG. 32 is a cross section view of the  
14       embodiment of the nebulization catheter shown in FIG. 31  
15       taken along the line a-a'.

16          FIG. 33 is sectional view of a distal end of an  
17       alternative embodiment of the nebulization catheter shown  
18       in FIG. 1.

19          FIG. 34 is sectional perspective view of a  
20       distal end of an alternative embodiment of the  
21       nebulization catheter and endotracheal tube shown in  
22       FIG. 2.

23          FIG. 35 is sectional view of a distal end of an  
24       alternative embodiment of the nebulization catheter shown  
25       in FIG. 1.

26          FIG. 37 is a cross section view of the  
27       embodiment of the nebulization catheter shown in FIG. 36  
28       taken along the line a-a'.

29          FIG. 38 is a perspective view of a distal end  
30       of an alternative embodiment of the nebulization catheter  
31       shown in FIGS. 36 and 37.

32          FIG. 39 is a perspective view of alternative  
33       embodiments of the nebulization catheter and endotracheal  
34       tube shown in FIGS. 37 and 38.

35          FIG. 40 is sectional perspective view of a  
36       distal end of an alternative embodiment of the  
37       nebulization catheter shown in FIG. 1.

1           FIG. 41 is a perspective view of alternative  
2       embodiments of the nebulization catheter and endotracheal  
3       tube of FIG. 1 shown in a patient's trachea.

4           FIG. 42 is a side view of an another embodiment  
5       of the nebulization catheter of FIG. 1 showing an  
6       alternative centering device.

7           FIG. 43 is a side view of an another embodiment  
8       of the nebulization catheter of FIG. 1 showing another  
9       alternative centering device.

10          FIG. 44 is a side view of an another embodiment  
11       of the nebulization catheter of FIG. 1 showing yet  
12       another alternative centering device.

13          FIG. 45 is a side view of the embodiment of  
14       FIG. 44 shown in another stage of operation.

15          FIG. 46 is a side view of a distal end of a  
16       nebulization catheter positioned in a patient's trachea  
17       illustrating an undesirable condition.

18          FIG. 47 is a perspective view similar to that  
19       of FIG. 40 of alternative embodiments of the nebulization  
20       catheter and endotracheal addressing the condition shown  
21       in FIG. 46.

22          FIG. 48 shows an alternative embodiment of the  
23       nebulizing catheter and endotracheal tube of FIG. 47  
24       positioned in a patient's trachea.

25          FIG. 49 shows an alternative embodiment of the  
26       nebulizing catheter of FIG. 6.

27          FIG. 50 is a diagram illustrating an embodiment  
28       of a drug reservoir and pressurization assembly that can  
29       be utilized in connection with the embodiment of the  
30       nebulization catheter of FIG. 1.

31          FIG. 51 is a diagram similar to that of FIG. 50  
32       illustrating an alternative embodiment of the drug  
33       reservoir and pressurization assembly.

34          FIG. 52 is a sectional view along line c-c' of  
35       FIG. 51.

1           FIG. 53 is a side view of an alternative  
2 embodiment of FIG. 1 including an optional humidification  
3 and heating arrangement.

4           FIG. 54 is a side view of a flow control system  
5 used in connection with the embodiment of FIG. 1 used for  
6 pressuring the liquid flow lumen.

7           FIG. 55 is a view similar to that of FIG. 54  
8 showing the flow control system of FIG. 54 in another  
9 stage of operation.

10          FIG. 56 is a perspective view of an alternative  
11 embodiment of the present invention illustrating an  
12 alternative method of use.

13          FIG. 57 is a perspective view illustrating an  
14 entire nebulization catheter system including sensors.

15          FIG. 58 shows a sectional view of an embodiment  
16 of a nebulizing catheter including a sensor.

17          FIG. 59 shows an alternative embodiment of the  
18 nebulizing catheter shown in FIG. 58.

19          FIG. 60 is a sectional view of a distal end of  
20 an alternative embodiment of the nebulizing catheter of  
21 FIG. 1.

22          FIG. 61 is a sectional view of an embodiment of  
23 the present invention that incorporates a baffle to  
24 generate a secondary aerosol.

25          FIG. 62 is a sectional view of another  
26 embodiment of the present invention that incorporates a  
27 baffle to generate a secondary aerosol.

28          FIG. 63 is a sectional view of yet another  
29 embodiment of the present invention that incorporates a  
30 baffle to generate a secondary aerosol.

31          FIG. 64 is a sectional view of still another  
32 embodiment of the present invention that incorporates a  
33 baffle to generate a secondary aerosol.

34          FIG. 65 is a diagram illustrating an embodiment  
35 of the present invention that incorporates a pressurized  
36 drug/propellant mixture canister.

1 FIG. 66 is a side view of an embodiment of a  
2 nebulizing catheter incorporated into of a suction  
3 catheter.

4 FIG. 67 is a detailed sectional view of the tip  
5 portion of the suction catheter - nebulizing catheter  
6 embodiment of FIG. 66.

7 FIG. 68 is a perspective view of the embodiment  
8 of FIG. 66 positioned in an endotracheal tube in a  
9 patient's respiratory system.

10 FIG. 69 is cross sectional view of the  
11 embodiment of FIG. 66 taken along lines a-a'.

12 FIG. 70 is a perspective view similar to FIG.  
13 68 showing the suction catheter advanced during an  
14 further stage of operation.

15 FIG. 71 is a side view of a proximal end of an  
16 endotracheal tube illustrating an arrangement of  
17 receiving a suction catheter and a nebulization catheter  
18 into the endotracheal tube.

19 FIG. 72 is an alternative embodiment of the  
20 arrangement shown in FIG. 71.

21 FIG. 73 is another alternative embodiment of  
22 the arrangement shown in FIG. 71.

23 FIG. 74 is another embodiment of a suction  
24 catheter incorporating aerosol delivery by nebulization.

25 FIG. 75 is still another embodiment of a  
26 suction catheter incorporating aerosol delivery by  
27 nebulization.

28 FIG. 76 is a sectional view of a distal end of  
29 an embodiment of a nebulizing catheter also incorporating  
30 a vibrating tip.

31 FIG. 77 is a sectional view of another  
32 embodiment of the nebulizing catheter incorporating  
33 micropulsation of the liquid supply.

34 DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED  
35 EMBODIMENTS

1        The present invention provides for the  
2        controlled and efficient delivery of an aerosolized  
3        medication to the lungs of a patient by nebulization of a  
4        medication at a distal end of a catheter positioned in  
5        the respiratory tract. Throughout this specification and  
6        these claims, the nebulization catheter is described as  
7        used for the delivery of medicine or medication. It is  
8        intended that the terms "medication", "medicine", and  
9        "drug" should be understood to include other agents that  
10       can be delivered to the lungs for diagnostic or  
11       therapeutic purposes, such as tracers, or for  
12       humidification.

13       I. Nebulizing Catheter - Basic Configuration

14       Referring to FIGS. 1 and 2, there is depicted a  
15       first embodiment of the present invention. FIGS. 1 and 2  
16       show an endotracheal tube 10 which may be a conventional  
17       endotracheal tube. The endotracheal tube 10 may have an  
18       inflatable cuff 12 located close to its distal end to  
19       facilitate positioning the tube 10 in the patient's  
20       trachea, or alternatively the endotracheal tube 10 may be  
21       of a type without an inflatable cuff. The inflatable  
22       cuff 12 is connected via a separate inflation lumen in  
23       the endotracheal tube 10 to a proximal fitting 13 for  
24       connection to a source of inflating gas (not shown). The  
25       endotracheal tube 10 has a proximal end connected to a  
26       manifold fitting 14. The fitting 14 has a port 15  
27       suitably adapted for connection to a ventilator circuit  
28       (not shown). The fitting 14 also includes another port  
29       16 that permits the introduction of a separate catheter  
30       into the endotracheal tube from the proximal end. The  
31       fitting 14 may be similar in construction to the elbow  
32       fitting described in U.S. Pat. No. 5,078,131 (Foley), the  
33       entire disclosure of which is incorporated herein by  
34       reference. In FIG. 1, a nebulizing catheter 20 is  
35       located in a position ready to be inserted into a  
36       ventilation lumen 22 of the endotracheal tube 10 via the

1 proximal fitting 14. In FIG. 2, the nebulizing catheter  
2 is positioned fully in the endotracheal tube 10 with a  
3 proximal end extending out of the port 16 of the proximal  
4 fitting 14.

5 At a proximal end of the nebulizing catheter 20  
6 is a manifold 24. The manifold 24 includes at least a  
7 gas port 28 and a liquid (medicine) port 32. These ports  
8 28 and 32 may include conventional attaching means, such  
9 as luer lock type fittings. In addition, these ports 28  
10 and 32 may also include closure caps 31 that may be used  
11 to close the ports when not in use and may be popped open  
12 when connection to a gas source or a liquid source is  
13 desired. Optionally, the manifold 24 may also include a  
14 filter located in-line with either the gas port 28 or the  
15 liquid port 32 or both ports to prevent lumen blockages  
16 by particulate matter. The nebulization catheter 20  
17 includes at least two separate lumens (as shown in FIG.  
18 2A). A first lumen 33 is used for conveyance of a liquid  
19 medicine and communicates with the port 32 on the  
20 manifold 24. The other lumen 34 is used for conveyance  
21 of a pressurized gas and communicates with the port 28 on  
22 the manifold 24. The liquid lumen 33 communicates with a  
23 distal liquid orifice 35 and the gas lumen 34  
24 communicates with a distal gas orifice 36 near a distal  
25 end 37 of the nebulization catheter 20. The distal  
26 opening 36 of the pressurized gas lumen 34 directs  
27 pressurized gas across the distal liquid lumen opening 35  
28 thereby nebulizing the liquid medication so that it can  
29 be delivered to the patient's lungs. The distal liquid  
30 orifice 35 may be open or may be provided with a porous  
31 material plug or a sponge-like or felt-like material plug  
32 which may extend slightly from the distal orifice and  
33 that allows liquid to flow from the orifice yet reduces  
34 the likelihood of liquid drooling from the tip.

35 The length of the nebulization catheter 20  
36 should be sufficient so that the distal end 37 can be  
37 located in the desired location in the respiratory system

1 while the proximal end (i.e., including the manifold 24)  
2 is accessible to the physician or other medical personnel  
3 for connection to suitable gas and liquid supplies  
4 external of the patient's body. Accordingly, the length  
5 of the nebulization catheter is dependant upon the size  
6 of the patient in which it is being used. A shorter  
7 nebulization catheter may be preferred in smaller  
8 patients, such as infants or children, and a longer  
9 nebulization catheter may be needed for adults. For  
10 example, a nebulization catheter suitable for adults may  
11 have a length of approximately 45 cm. In one embodiment,  
12 approximately 30 cm of the nebulizing catheter 20 is in  
13 the endotracheal tube 10. The nebulization catheter may  
14 be introduced into the respiratory system through a  
15 patient's mouth or via a tracheostomy tube or through the  
16 nasal passages. The nebulization catheter may also be  
17 used to deliver an aerosol to a patient's nasal passages  
18 in which case the length may be correspondingly shorter.

19 As explained in more detail below, the  
20 generation of an aerosol plume with the desired geometry,  
21 particle size, velocity, etc., requires that the distal  
22 gas and liquid orifices have small dimensions. Also as  
23 explained below, the distal gas orifice 36 and the distal  
24 liquid orifice 35 should be in close proximity to each  
25 other in order to produce an aerosol with the desired  
26 characteristics and efficiency. Further, in order to  
27 provide the desired medicine delivery rates and to  
28 operate with reasonably available pressure sources, the  
29 liquid and gas lumens in the nebulizing catheter should  
30 be as large as possible, consistent with anatomical  
31 requirements. Accordingly, the nebulization catheter 20  
32 has a multiple stage construction with a larger shaft  
33 size and larger lumens in a main shaft section and a  
34 smaller shaft size and smaller lumens in a distal shaft  
35 section.

36 As shown in FIG. 2A, the nebulizing catheter 20  
37 is composed of a shaft 38 having a main section 39 and a

1 distal section 40. In the main shaft section 39 of the  
2 nebulization catheter, the liquid and gas lumens 33 and  
3 34 have a larger size than in the distal shaft section  
4 40. For example, in the main shaft section 39, the  
5 liquid and gas lumens each may have an I.D. of  
6 approximately .010 to .030 inches. At a most proximal  
7 end where the main shaft section 39 connects to the  
8 manifold 24, the lumens may be even larger. In the  
9 distal shaft section 40, the liquid and gas lumens taper  
10 to a much smaller I.D. with the liquid lumen  
11 approximately .002 to .008 inches or even smaller and the  
12 gas lumen .002 to .020 inches. In a preferred  
13 embodiment, the liquid and gas orifices 35 and 36 are  
14 less than .125 inches apart, and more preferably less  
15 than .030 inches apart, and in a most preferred  
16 embodiment less than .001 inches apart. In a nebulizing  
17 catheter having an overall length of 45 cm, the main  
18 shaft section 39 may be approximately 25 cm and the  
19 distal shaft section 40 may be approximately 20 cm.  
20 Also, although the liquid and gas lumens are shown to be  
21 side by side in FIG. 2A, they may also be constructed to  
22 have an coaxial or other arrangement. Further, although  
23 the main shaft section 39 is shown to be of a uniform  
24 diameter and profile, alternatively it may also have a  
25 tapered diameter and profile such that the entire shaft  
26 38 is tapered along its length.

27 In a first preferred embodiment of the  
28 invention, as shown in FIGS. 1 and 2, the nebulizing  
29 catheter 20 is removable, and replaceable with respect to  
30 the endotracheal tube 10. This provides several  
31 significant advantages. First, the nebulizing catheter  
32 20 may be specifically adapted and chosen to have the  
33 desired operating characteristics suitable for delivery  
34 of the particular medication being administered to the  
35 patient. In addition, the fact that the nebulizing tube  
36 20 is removable and replaceable provides versatility and  
37 flexibility regarding the therapy and dosage regime that

1 can be chosen by the physician. For example, a decision  
2 by the physician whether to deliver a medication to the  
3 respiratory tract, and the selection of the type and  
4 dosage of the medication to be delivered, need not be  
5 made by the physician until after the endotracheal tube  
6 is already in place in the patient. When the physician  
7 determines the proper type of medication to be delivered  
8 to the patient via the respiratory tract, the appropriate  
9 nebulization catheter can be selected and inserted into  
10 the endotracheal tube. Further, the nebulizing catheter  
11 20 can be removed after it is used and therefore it is  
12 not necessary for the nebulization catheter to be left in  
13 the patient and occupy space in the patient's respiratory  
14 tract or in the endotracheal tube 10 when it is no longer  
15 needed. In addition, the decision regarding the proper  
16 type of medication can be revisited again at any time  
17 after the endotracheal tube is in place. If a different  
18 type of nebulizing catheter is required, such as for  
19 sterility purposes, the endotracheal tube need not be  
20 replaced as well.

21 Another advantage of providing the nebulization  
22 catheter as a separate, removable device is that it can  
23 be accommodated in a variety of other instruments and/or  
24 devices. For example, the nebulization catheter of FIGS.  
25 1 - 5 is shown used in an endotracheal tube; however, the  
26 nebulization catheter could also be positioned inside of  
27 a bronchoscope, such as in a working channel of a  
28 bronchoscope. The nebulizing catheter could be  
29 positioned in any instrument that is positioned in the  
30 respiratory tract and that can accommodate the nebulizing  
31 catheter size.

32 The nebulizing catheter may be provided with  
33 radiopaque markings 41 to facilitate positioning and  
34 placement. The radiopaque markings 41 may be provided by  
35 radiopaque bands of metal or heat shrunk bands of doped  
36 radiopaque plastic that are attached to the nebulizing  
37 catheter, or alternatively the markings may be provided

1 by doping the plastic material of the nebulizing catheter  
2 with a radiopaque material. Alternatively, a radiopaque  
3 dye may be added to the liquid being delivered by the  
4 nebulization catheter to assist observation. The  
5 markings 41 may be graduated to facilitate recognition,  
6 or alternatively may extend over a portion or all of the  
7 nebulizing catheter. In still a further embodiment, the  
8 markings may be formed of a ultrasonic reflectors, e.g.  
9 textured material, that are visible by means of  
10 ultrasonic imaging. The nebulization catheter may also  
11 include a stripe 43 extending along a side of the shaft  
12 (as shown in FIGS. 5 and 6). The stripe 43 may be  
13 radiopaque or ultrasonically visible and may be used to  
14 determine the rotational orientation of the shaft. The  
15 stripe may be formed by a coextrusion process or by  
16 embedding a wire in the wall of the nebulization  
17 catheter.

18 One method that may be employed to facilitate  
19 positioning of the nebulization catheter is to monitor  
20 the pressure at the distal end of the endotracheal tube  
21 as the nebulization catheter is being advanced.  
22 Monitoring the pressure at the end of the endotracheal  
23 tube may be accomplished through one of the endotracheal  
24 tube lumens. The gas source connected to the proximal  
25 end of the nebulization catheter may be operated so as to  
26 expel a gas from the distal end of the nebulization  
27 catheter as it is being advanced. The gas being expelled  
28 from the distal end of the nebulization catheter affects  
29 the pressure being detected through the endotracheal  
30 tube. When the distal end of the nebulization catheter  
31 passes the distal end of the endotracheal tube, the  
32 pressure being measured through the endotracheal tube  
33 abruptly changes thereby providing a clear indication of  
34 the location of the distal end of the nebulization  
35 catheter relative to the endotracheal tube.

36 The nebulizing catheter may also include a  
37 safety stop 44 located along a proximal portion that

1 engages a portion of the endotracheal tube proximal  
2 portion or a fitting thereon, as shown in FIG. 2. The  
3 safety stop 44 ensures that the distal end of the  
4 nebulizing catheter 20 is correctly positioned with  
5 respect to the distal end 46 of the endotracheal tube 10  
6 and prevents the distal end 37 of the nebulizing catheter  
7 from extending too far into the trachea. In addition to  
8 the safety stop 44, the proximal portion of the  
9 nebulizing catheter 20 may also have graduated markings  
10 48 that would be visible to the physician handling the  
11 proximal end of the nebulizing catheter to enable a  
12 determination of the position of the distal end 37 of the  
13 nebulizing catheter 20 relative to a distal end 46 of the  
14 endotracheal tube 10.

15 The nebulizing catheter 20 may also include a  
16 critical orifice 49 located at a proximal portion of the  
17 nebulizing catheter. The critical orifice 49 may be  
18 formed by a small critical opening located in line with  
19 the gas pressurization lumen 34 of the nebulizing  
20 catheter shaft close to the manifold 24. The critical  
21 orifice 49 is sized so that if the nebulization catheter  
22 is supplied with a flow in excess of its designed  
23 operating flow, the critical orifice will allow only the  
24 designed operating flow to pass through to the distal gas  
25 orifice. Alternatively, a safety valve may be located  
26 in the proximal portion of the catheter shaft. The  
27 safety valve would be designed to open if supplied with  
28 an excess of pressure.

29 In addition, the nebulizing catheter may  
30 include a centering device 50. The centering device 50  
31 is located close to a distal end of the nebulizing  
32 catheter shaft and helps to center and align the distal  
33 end of the nebulizing catheter for improved performance,  
34 as explained in more detail below.

35 According to one embodiment, the removable  
36 nebulization catheter 20 is enclosed in a storage sheath  
37 51. The storage sheath 51 may be similar to the type of

1 storage sheaths used in conjunction with suction  
2 catheters. The storage sheath is preferably flexible,  
3 collapsible, or extendable to accommodate insertion of  
4 the catheter. The storage sheath 51 may be connected to  
5 the fitting 14. The storage sheath 51 can be used to  
6 receive the nebulizing catheter 20 when it is being  
7 withdrawn from the endotracheal tube 10. The storage  
8 sheath 51 is sealed and can maintain the withdrawn  
9 nebulizing catheter in an isolated condition when it is  
10 temporarily removed from the patient's respiratory  
11 system. The storage sheath 51 also allows the physician  
12 to re-insert the nebulization catheter into the patient.  
13 In this manner, the nebulization catheter can be reused  
14 in a limited way with respect to a patient and can be  
15 maintained in a sterile condition while withdrawn from  
16 the patient. The storage sheath 51 may have a distal  
17 sleeve 53 that can slide along the shaft of the  
18 nebulization catheter so that the nebulization catheter  
19 may be advanced into the ventilation lumen of the  
20 endotracheal tube or withdrawn into the storage sheath  
21 51. The sleeve 53 may have a close fitting seal 55  
22 located therein which is designed to clean and/or wash  
23 the nebulization catheter when it is withdrawn into the  
24 sheath. Alternatively, a cleaning seal 55 may be located  
25 in the port 16 of manifold fitting 14.

26 Another feature that may be used in conjunction  
27 with certain procedures is radiation shielding. Some  
28 procedures for which the nebulization catheter may be  
29 used may involve the delivery of radioactive agents, e.g.  
30 tracers to the lungs. To minimize exposure to  
31 radioactive materials, the nebulizing catheter may be  
32 provided with shielding over all or a significant portion  
33 of the overall length of the catheter. Shielding may  
34 also be provided at the liquid source reservoir.

35 The nebulizing catheter is preferably  
36 constructed of a biocompatible, chemically resistant  
37 polymer in order that it is suitable for use with a wide

1 variety of drugs. The catheter shaft is preferably clear  
2 to allow visualization of contaminants or blockages of  
3 the interior lumens. Also, the portion of the catheter  
4 shaft that forms the liquid lumen 33 is preferably  
5 composed of a relatively non-compliant material. In a  
6 present embodiment, the catheter shaft is composed of a  
7 polymer such as polyethylene or nylon. A polymer tubing  
8 is extruded with multiple lumens to be used for the  
9 separate gas and liquid lumens. In order to produce a  
10 nebulization catheter with the tapered distal section 40,  
11 a multi-lumen extruded tubing may be drawn down in a  
12 portion thereof to form the tapered distal section 40.  
13 The draw down ratio may be selected to provide a  
14 nebulization catheter shaft with the desired dimensions.  
15 The draw down process serves to make the lumens smaller  
16 in size distally as well as closer together while  
17 maintaining the proximal cross sectional profile of the  
18 multi-lumen tubing. The larger proximal profile provides  
19 for greater pushability in the catheter shaft and  
20 facilitates manufacturing by making the manifold  
21 connection easier. The draw down ratio used on the  
22 extruded polymer tubing may be on the order of 2-to-1, 5-  
23 to-1, or even as high as 20-to-1 or higher. Prior to  
24 drawing down, the extruded polymer tubing is preferably  
25 exposed to high energy radiation to crosslink the polymer  
26 molecules to provide for favorable material properties,  
27 such as the ability to maintain orifice dimensions and  
28 tolerances. The radiation may have an energy of  
29 approximately 10-700 kgy. After the crosslinking step,  
30 the tubing is heated to its transition temperature  
31 between its melt and glass states, and is drawn down by  
32 the desired ratio.

33 As an alternative to drawing down the extruded  
34 tubing, the multi-stage nebulization catheter shaft may  
35 be formed by a bubble extrusion process wherein the  
36 desired tapered distal section is formed directly in the  
37 shaft as it is being extruded. Again, this process may

1 be used for manufacturing efficiency and convenience. As  
2 another alternative, the multi-stage shaft may be formed  
3 by a combination of both bubble extrusion and drawing  
4 down. Still another alternative for forming the desired  
5 tapered profile for the nebulizing catheter shaft is to  
6 use a material that can be cold drawn in order to cause a  
7 sharp neck down in diameter, such as a linear low density  
8 polyethylene. Although the process for forming the  
9 tubing is particularly suited for producing a  
10 nebulization catheter shaft for use in delivering  
11 medicine to the respiratory tract, it should be  
12 understood that the process could be used to produce  
13 aerosol nozzles for non-medical purposes as well.

14 Alternatively, all or part of the nebulization  
15 catheter shaft can be molded, especially at locations  
16 where close tolerances are preferred such as at the tip.

17 After the shaft is formed with the desired  
18 stages, it is cut and assembled with the other components  
19 of the nebulizing catheter. Although the nebulization  
20 catheter is preferably constructed of a polymer, in an  
21 alternative embodiment it could be formed of other  
22 materials such as a metal, especially a malleable metal  
23 to facilitate drawing, shaping or forming orifices.  
24 During the manufacturing process, the nebulizing catheter  
25 may be pre-sterilized by means of a conventional process,  
26 such as a gamma ray or electron beam. The nebulizing  
27 catheter is preferably disposable after use with a single  
28 patient, but may be reused to a limited extent with a  
29 single patient provided that contamination can be  
30 prevented such as through the use of the sheath 51,  
31 described above. The nebulizing catheter shaft  
32 preferably possesses torsional rigidity so that rotation  
33 of the proximal end is transmitted at a 1:1 ratio to the  
34 distal end. The nebulizing catheter may also be provided  
35 with an antiseptic coating.

36 Drug delivery rates are closely related to the  
37 particle size with larger particles providing greater

1 delivery rates. The embodiments of the nebulization  
2 catheter described herein have the capability of  
3 generating particle distributions with a GSD between 2  
4 and 2.5. Drug delivery rates in a range between  
5 approximately 5 and 1000 mg (.005 - 1.0 ml) per minute  
6 may be obtained. A variety of particle size  
7 distributions can be generated at most flow rates through  
8 selection of the catheter type and aerosol volume output.  
9 An aerosol of this type can be generated with the  
10 nebulization catheter using a gas flow rate as low as 0.1  
11 liter/minute.

12 There are a number of factors that affect the  
13 particle size generated. These factors include: (1) the  
14 gas orifice diameter, (2) the liquid orifice diameter,  
15 (3) the liquid delivery tube outer diameter and geometry,  
16 (4) the distance between the gas and liquid orifices, (5)  
17 the rate of gas delivery, and (6) the pressure of the  
18 liquid. Of course, the size of the solid particles in  
19 suspension, if present, in the liquid are a defining  
20 aspect of the aerosol particle size generated. In  
21 addition, there are other factors that affect the aerosol  
22 particle size such as the characteristics of the liquid,  
23 e.g. viscosity, suspension, surface tension and the  
24 composition of the driving gas, however, these factors  
25 affect the particle size of the aerosol generated to a  
26 lesser degree. By selectively varying these parameters,  
27 the size and size distribution of the aerosol particles  
28 can be changed from less than a micron to at least 10  
29 microns.

30 The embodiments of the present invention,  
31 described herein are suitable for delivery of an aerosol  
32 by nebulization with a volumetric particle size  
33 distribution comparable to other nebulization systems.  
34 Further, by generating an aerosol at a location in the  
35 trachea or even deeper in the bronchi, impaction losses  
36 in tract can be avoided. By reducing impaction losses,  
37 it may be acceptable to use larger particle sizes (e.g.

1 greater than 5 microns). The combination of lower  
2 impaction losses and larger particle sizes may provide  
3 higher effective delivery rates than prior systems.  
4 Reducing impaction losses would enable an embodiment of  
5 the nebulization catheter to provide acceptable delivery  
6 rates with aerosol particle sizes greater than 5 microns.

7 Referring to FIGS. 3 - 5, there is depicted a  
8 further embodiment of the present invention. According  
9 to the embodiment of FIGS. 3 - 5, there is provided an  
10 endotracheal tube 52 and a nebulizing catheter. The  
11 nebulizing catheter may be similar to the nebulizing  
12 catheter 20 shown in FIGS. 1 through 3. In the  
13 embodiment of FIGS. 3 - 5, the endotracheal tube 52 has  
14 an auxiliary lumen 56 in addition to its main ventilation  
15 lumen 60. Some endotracheal tubes provide auxiliary  
16 lumens through the shaft wall. The auxiliary lumen 56 is  
17 preferably sized and adapted to receive the separate  
18 nebulization catheter 20. This embodiment provides many  
19 of the same advantages as the embodiment of FIGS. 1  
20 through 3. In addition, in this embodiment, the  
21 auxiliary lumen 56 may be provided with a distal aperture  
22 64 that facilitates locating and aligning the distal end  
23 of 37 the nebulizing catheter 20 at a desired location  
24 for nebulization purposes.

25 In the embodiments of the invention shown in  
26 FIGS. 1-5, the nebulizing catheter 20 is shown used in  
27 conjunction with an endotracheal tube either of a  
28 conventional type 10, as in FIGS. 1 and 2, or of a type  
29 especially designed for use with the nebulizing catheter  
30 such as endotracheal tube 52 of FIGS. 3 - 5. The  
31 nebulizing catheter 20 according to an embodiment of the  
32 present invention may also be used without a separate  
33 endotracheal tube, i.e. the nebulizing catheter may be  
34 used on a patient who is not intubated, as shown in FIG.  
35 6. If used on a spontaneously breathing patient (without  
36 an endotracheal tube), the patient should be properly

1 anesthetized and/or that the airway passage of the  
2 patient be topically anesthetized. The nebulizing  
3 catheter 20 is positioned in the respiratory system of a  
4 patient directed past the carina 68 into one of the  
5 bronchi 72 of the lungs. Alternatively, the nebulizing  
6 catheter 20 may also be positioned proximal of the carina  
7 in the trachea, as desired. Embodiments of the  
8 nebulizing catheter may also be used on patients who have  
9 had tracheotomies or who have tracheotomy tubes.

10 In the embodiment of FIG. 6, a guiding sheath  
11 73 is used. The guiding sheath 73 is used to help  
12 position the nebulizing catheter 20 in the respiratory  
13 system of the patient. The guiding sheath 73 includes a  
14 lumen through which the nebulization catheter 20 can be  
15 advanced into a desired bronchi site. To facilitate  
16 positioning the nebulization catheter, the guiding sheath  
17 73 may have a pre-shaped distal end to facilitate  
18 locating the sheath in the desired airway passage.  
19 Alternatively, the guiding sheath 73 may have a distal  
20 end that can be formed into a desired shape by the  
21 physician just prior to insertion. The guiding sheath 73  
22 differs from the endotracheal tube 10 of FIGS. 1-5 in  
23 that it may have a smaller outside diameter so that it  
24 can be advanced into smaller airway passages deep in the  
25 patient's bronchi past the carina 68. The inside  
26 diameter of the sheath 73 is large enough to advance the  
27 nebulization catheter. The guiding sheath 73 is  
28 particularly useful when the nebulization catheter 20 is  
29 being located deep in the patient's lungs, or when the  
30 nebulization catheter is used without an endotracheal  
31 tube. The guiding sheath 73 may also be used with an  
32 endotracheal tube through the ventilation lumen thereof.  
33 The guiding sheath is preferably composed of a  
34 torsionally rigid material so that the distal end of the  
35 guiding sheath is responsive to rotation at the proximal  
36 end.

1 Referring to FIGS. 7 and 8, there is shown  
2 another embodiment of the nebulizing catheter. In the  
3 embodiment of FIG. 7, a nebulizing catheter 76 includes  
4 an occlusion balloon 80 located on a distal exterior  
5 surface of the nebulizing catheter shaft body 84. The  
6 nebulizing catheter 76 may include an additional lumen  
7 88, as shown in FIG. 8, located therethrough and  
8 communicating with the interior of the balloon 80 for  
9 providing inflation fluid, i.e. preferably gas, to expand  
10 the occlusion balloon 80. This lumen 88 for inflation  
11 fluid is in addition to the lumens 92 and 96 in the  
12 catheter shaft 84 used for conveyance of the liquid  
13 medicine and pressurized gas, respectively. The  
14 occlusion balloon 80 may be used to position the  
15 nebulizing catheter in the appropriate respiratory branch  
16 100, center the nebulizing catheter tip for proper  
17 orientation, and isolate a particular bronchus, as  
18 needed. The embodiment of the nebulizing catheter 76  
19 shown in FIG. 7 may be used with an endotracheal tube in  
20 a manner similar to that shown in FIGS. 1-3, or  
21 alternatively it may be used without a separated  
22 endotracheal tube, similar to the embodiment of FIG. 6.  
23 When used without a separate endotracheal tube, the  
24 nebulizing catheter 76 of FIG. 7 could be used for the  
25 purpose of selective ventilation of one of the bronchi of  
26 the lungs even without providing aerosolization.  
27 Alternatively, the nebulization catheter 76 could provide  
28 aerosolization on an intermittent basis with continuous  
29 ventilation. If the nebulization catheter is used to  
30 provide ventilation as well as aerosolized medication,  
31 the ventilation regime can be tailored to maximize  
32 aerosol transport.

33 In addition, to further facilitate positioning  
34 and placement, the nebulizing catheter 76 may be used  
35 with a guide wire 104. The nebulizing catheter may be  
36 provided with a separate guide wire lumen 108 to receive  
37 the guide wire 104, or alternatively, the guide wire may

1 use one of the existing lumens that is also used for  
2 either the pressurized gas or the liquid or alternatively  
3 the guide wire may be incorporated and fixed into the  
4 nebulizing catheter so that it is non-removable. The  
5 guide wire, whether of the removable type or the type  
6 that is fixed to the nebulizing catheter, may also be  
7 steerable, i.e. so that it can be guided from a proximal  
8 end to access the appropriate location in the lungs. The  
9 steering apparatus may utilize selective tensioning of a  
10 pull wire, etc. from a proximal end. If the guide wire  
11 is of the separate removable type, it may be withdrawn  
12 after it has been used to position the distal tip of the  
13 nebulizing catheter so as to avoid interfering with  
14 aerosol delivery. In addition, the distal tip of the  
15 guide wire or nebulization catheter may be pre-shaped or  
16 shapable by the physician so as to impart an appropriate  
17 curve or bend to facilitate access to the desired airway.

18 Referring to FIG. 9, there is shown another  
19 embodiment of a nebulizing catheter of FIG. 7. The  
20 embodiment of FIG. 9 is similar to the embodiment of FIG.  
21 7 with the exception that the separate guide wire 104 is  
22 received in a loop 106 located close to a distal end of  
23 the nebulizing catheter 76. Proximal of the loop 106,  
24 the guide wire 104 is positioned adjacent to the shaft 84  
25 of the nebulizing catheter 76. Instead of a loop 106,  
26 the guide wire may be received in a short lumen located  
27 in the distal end of the nebulizing catheter.

28 II. Generation of Aerosol Plume

29 It has been discovered that the shape of the  
30 aerosol plume can be a significant factor affecting the  
31 rate and efficacy of the delivery of medication by an  
32 aerosol. In general, it is preferable to generate an  
33 aerosol that has a shape that minimizes particle  
34 impaction near the distal tip of the nebulizing catheter,  
35 given the location of the tip and the airflow conditions  
36 around it. For example, if the aerosol plume is wide, a

1 portion of the drug may be wasted in the end of the  
2 endotracheal tube or on the wall of the trachea or other  
3 airway passage. On the other hand, if the plume is too  
4 narrow or the velocity too high, a portion of the drug  
5 may impact excessively on the patient's carina. In  
6 general, a low aerosol particle velocity is desirable.  
7 One of the reasons for this is to avoid impacting the  
8 carina with the discharge of high velocity aerosol  
9 particles. In addition, it is also generally desirable  
10 to have as wide an aerosol plume as possible while  
11 avoiding significant impact with the walls of either the  
12 endotracheal tube or the respiratory airway passage. The  
13 effects of aerosol plume velocity and geometry are  
14 related to anatomical factors. In some circumstances,  
15 e.g. away from the carina, a narrow, fast aerosol plume  
16 may be preferable to a slower, wider plume.

17 Regarding the embodiments described below,  
18 certain of the embodiments may be preferable from the  
19 standpoint of versatility, i.e. they may be able to  
20 deliver a variety of medications having different  
21 viscosities, suspensions, surface tensions, etc. Others  
22 of the embodiments may be more suitable for the delivery  
23 of specific types of medications or the delivery of  
24 particles of certain sizes.

25 Referring to FIG. 10, there is shown a tip  
26 configuration for a nebulizing catheter 112. The  
27 nebulizing catheter 112 may be either a stand alone-type  
28 of nebulizing catheter, similar to the catheters shown in  
29 FIGS. 6 and 10, or may be incorporated into an  
30 endotracheal tube either removably, as in FIGS. 1 - 5, or  
31 non-removably. In the embodiment of FIG. 10, the  
32 nebulizing catheter 112 has a coaxial configuration.  
33 Specifically, the nebulizing catheter 112 includes an  
34 outer tubular member 116 defining a lumen 120 and an  
35 inner tubular member 124 also defining a lumen 128. The  
36 inner tubular member 124 is located in the lumen 120 of  
37 the outer tubular member 116. According to the

1 embodiment shown FIG. 6, pressurized gas is conveyed in  
2 the annular region defined between the inner and outer  
3 tubular members. Liquid medication is conveyed in the  
4 lumen 128 of the inner member 124. As shown in the  
5 embodiment of FIG. 10, a distal end of the outer tubular  
6 member 116 is approximately adjacent to a distal end of  
7 the inner tubular member 124. In the embodiment of FIG.  
8 10, the outer tubular member 116 has an O.D. of  
9 approximately .008 inches and an I.D. of approximately  
10 .006 inches. The inner tubular member 124 has an O.D. of  
11 approximately .003 inches and I.D. of approximately .0015  
12 inches. Both the inner tubular member 124 and the outer  
13 tubular member 116 have larger dimensions proximal of the  
14 distal tip portion. Along a main shaft portion proximal  
15 of the distal tip, the outer tubular member 116 has an  
16 O.D. of approximately .115 inches and an I.D. of .080  
17 inches and the inner tubular member 124 has an O.D. of  
18 approximately .060 inches and an I.D. of .050 inches.

19 The embodiment of FIG. 11 shows a tip of a  
20 nebulizing catheter 132. This embodiment is similar to  
21 the embodiment of FIG. 10. The tip 133 is formed with a  
22 plurality of lumens terminating in a plurality of  
23 orifices. An inner lumen 134 is used to convey the  
24 liquid medication and the surrounding lumens 135 convey  
25 the pressurized gas used to nebulize the liquid. This  
26 embodiment has the advantage that the orifice of the  
27 liquid lumen 134 is centered with a fixed spacing  
28 relative to the orifices of the gas lumens 135 around it.  
29 In the embodiment of FIG. 11, the multiple lumen  
30 construction may extend all the way back to the proximal  
31 end of the nebulizing catheter 132 or alternatively, only  
32 a distal segment may have the multiple gas lumen  
33 configuration in which case the pressurized gas may be  
34 conveyed through a single proximal lumen that connects to  
35 the multiple distal lumens.

1 FIGS. 12 and 13 show an alternative embodiment  
2 136 of the multiple lumen nebulization catheter in FIG.  
3 11. The embodiment in FIGS. 12 and 13 is useful when it  
4 is desired to provide the aerosol medicine with a pulsed  
5 delivery. The pulsed delivery may be timed to coincide  
6 with the inhalation of the patient so that aerosol is not  
7 wasted when the patient is exhaling. A potential  
8 drawback with pulsed delivery is that the aerosol may  
9 drool from the tip of the nebulizing catheter when the  
10 pressure being applied to the liquid is reduced to effect  
11 the pulsation. To avoid this potential problem, the  
12 nebulizing catheter 136 provides for closure of the  
13 liquid lumen when the pressure being applied to it is  
14 reduced. As in the previously described embodiment, the  
15 nebulization catheter 136 in FIGS. 13 and 14, has a  
16 centrally located lumen 137 for delivery of a liquid  
17 medicine and a plurality of lumens 138 surrounding the  
18 central lumen 137 for conveyance of a pressurized gas to  
19 nebulize the liquid at the distal orifice 139. In this  
20 embodiment, the catheter 137 is formed of a low  
21 compliance material in the outer wall area 140 and a  
22 relatively high compliance material in the area 141  
23 surrounding the centrally located liquid lumen 137.  
24 These differing compliance characteristics may be formed  
25 in the catheter shaft by coextruding a single tube with  
26 different materials. When using the embodiment of FIGS.  
27 12 and 13, a constant, relatively high pressure is  
28 applied to the gas in the lumens 138. Liquid medicine is  
29 delivered via the lumen 137 and pressure pulses are  
30 applied to the liquid from an external delivery source,  
31 such as a pump. When the pressure in the liquid lumen  
32 137 is low, the high pressure in the gas lumens 138  
33 deform the compliant inner material 141 thereby  
34 compressing the liquid lumen 137 and closing it off, as  
35 shown in FIG. 12. When a pressure pulse is applied to  
36 the liquid in the lumen 137, it overcomes the compressive  
37 forces from the gas lumens 138 allowing the lumen 137 to

1 open and permitting the liquid medicine to be delivered  
2 to the distal orifice 139 to be nebulized, as shown in  
3 FIG. 13. In this manner, the embodiment of FIGS. 12 and  
4 13 provides for pulsed liquid nebulization with reduced  
5 possibility of drooling.

6 Another feature shown in FIGS. 11 and 12 is a  
7 porous plug 142 located in the liquid orifice 139. This  
8 porous plug may be made of a felt-like material and may  
9 assist in the production of fine aerosol particles.

10 The embodiment of FIG. 14 shows a distal tip of  
11 another embodiment of the nebulizing catheter. In this  
12 embodiment, a nebulizing catheter 148 includes a main  
13 shaft section 152 and a distal shaft section 156. The  
14 distal shaft section 156 is tapered to a tip 160. At the  
15 tip 160, a liquid orifice 164 is surrounded by a  
16 plurality of gas orifices 168. In a preferred  
17 embodiment, there are six gas lumens terminating in the  
18 six orifices 168. In this embodiment, the liquid orifice  
19 164 has a diameter of approximately .002 inches and the  
20 gas orifices 168 each have a diameter of approximately  
21 .002 inches. This embodiment is similar to the  
22 embodiment of FIG. 11 except that the distal section 156  
23 provides for a reduction in the tip size and  
24 corresponding modification of the nebulization plume  
25 properties. This reduction is preferable as it provides  
26 a smaller orifice size.

27 The embodiment of FIG. 15 shows a distal  
28 portion of a nebulizing catheter 172. In this  
29 embodiment, the nebulizing catheter includes a proximal  
30 shaft section 176 and a distal shaft section 180. The  
31 proximal shaft section 176 includes a plurality of lumens  
32 184. A central one 188 of the plurality of lumens 184 is  
33 used to convey liquid medicine and the remainder of the  
34 lumens surrounding it are used to convey gas. The distal  
35 shaft section 180 connects to the distal end of the

1 proximal shaft section 176 and defines a tapered cavity  
2 192 between the distal end of the proximal shaft section  
3 176 and a distal orifice 196. At least one of the  
4 plurality of lumens 184 is used to convey a pressurized  
5 gas that is discharged into the cavity 192. A tubular  
6 extension 200 extends the liquid lumen through the cavity  
7 192 and distally out the orifice 196. The orifice 196 is  
8 sized to provide an annular region around the tubular  
9 extension 200 to permit the pressurized gas to flow  
10 through to nebulize the liquid medication that exits a  
11 distal orifice 204 of the tubular extension 200. In a  
12 preferred embodiment, the distal shaft section 180 is  
13 composed of stainless steel and the orifice has an I.D.  
14 of .025 inches. The tubular extension 200 has an O.D. of  
15 .012 inches and an I.D. of .007 inches. This embodiment  
16 has the advantage of combining a relatively small distal  
17 profile with a relatively large proximal flow channel.  
18 Another advantage of this embodiment is that it provides  
19 for a balanced airflow around the liquid orifice 204.

20 FIG. 16 shows yet another embodiment for a tip  
21 for a nebulizing catheter. In FIG. 16, a nebulizing  
22 catheter 208 has a coaxial configuration similar to the  
23 embodiment of FIG. 10 (although it could also have a  
24 configuration similar to that of other coaxial  
25 embodiments, e.g. FIGS. 11, 14, or 15). In FIG. 16, a  
26 thin solid wire or filament 212 is located at a distal  
27 end of a liquid orifice 216 located at a distal end of an  
28 inner tubular member 220. The tapered wire 212 extends a  
29 short distance distally from the distal end of the inner  
30 tubular member 220. The tapered wire 212 is located with  
31 respect to the liquid orifice 212 so that liquid being  
32 conveyed through the inner member 220 continues to flow  
33 distally of the distal orifice 216 along the wire 212,  
34 i.e. adhering to it by surface tension. Of course, once  
35 the liquid reaches a distal tip 224 of the wire 212, it  
36 is entrained and nebulized by the gas flow from the

1 annular region 228 defined between the inner tubular  
2 member 220 and an outer tubular member 232. As mentioned  
3 above, one of the factors that affects the nebulization  
4 plume particle size and geometry is the size of the  
5 distal liquid orifice. In general, a smaller liquid  
6 orifice produces smaller particles and a narrow aerosol  
7 plume cone. In the embodiment of FIG. 16, the thin wire  
8 212 carries only a small amount of liquid along it so  
9 that it functions similarly to an orifice of a very small  
10 size. Accordingly, the embodiment of FIG. 16 has the  
11 potential for producing an aerosol of very fine  
12 particles. In the embodiment of FIG. 16, the outer  
13 tubular member has an I.D. of approximately .020 inches.  
14 The inner tubular member has an I.D. of approximately  
15 .006 inches. The thin wire has an O.D. of approximately  
16 .002 inches. The wire or filament 212 may be composed of  
17 a metal wire or a polymer wire, such as a polyolefin  
18 fiber like Spectra fiber. Alternatively, the filament  
19 212 may be composed of a porous or felt-like material,  
20 such as nylon or Porex, in which case it may be wider in  
21 diameter than if made of a solid material.

22 FIG. 17 shows an alternative embodiment of the  
23 embodiment of FIG. 16. In FIG. 17, there is a distal end  
24 of a nebulizing catheter 236 having a tapered wire or  
25 filament 240 located at the distal end of a lumen of an  
26 inner tubular member 244. The tapered wire 240 in this  
27 embodiment has a curved shape that is designed to whip in  
28 a spiral when it is in a flow of air. In the embodiment  
29 of FIG. 17, when pressurized gas flows through the  
30 annular region 248, it causes the tapered wire 240 to  
31 whip around with a spiral motion. The length of the wire  
32 240 is chosen so that it does not impact the wall of the  
33 trachea or other airway passage when it moves in a spiral  
34 whipping motion. In one embodiment, the wire 240 has a  
35 length of approximately 1 - 2 mm. The tapered wire 240  
36 carries the liquid out to its tip for entrainment, and

1 the nebulization plume is formed with a conical shape.  
2 The width of the plume may be changed by changing the  
3 length of the filament 240. The speed of the spiral  
4 motion can be controlled by appropriate selection of wire  
5 stiffness and air foil shape. In general, the spiral  
6 plume produced by the embodiment of FIG. 17 will be wider  
7 than the embodiment of FIG. 16 and have less forward  
8 velocity. Both these characteristics may be favored in a  
9 nebulization catheter.

10 FIGS. 18 and 19 show another embodiment of the  
11 nebulization catheter. In this embodiment, a  
12 nebulization catheter 252 has a coaxial configuration  
13 formed of an outer tubular member 256 and an inner  
14 tubular member 260. A distal plug 264 fits into a distal  
15 end of the annular region 268 forming the gas lumen. A  
16 plurality of apertures 272 extend through the plug 264 to  
17 form distal gas orifices. Located in a lumen 276 defined  
18 by the inner tubular member 260 is a retractable wire or  
19 pin 280. The wire 280 is preferably a solid wire of a  
20 rigid material. For example, the wire may be composed of  
21 a metal, such as stainless steel, a polymer, or a  
22 radiopaque material. A distal end 284 of the inner  
23 member 260 is tapered and may extend distally of the plug  
24 264 or alternatively may extend only to the distal end of  
25 the inner tubular member 260 or even proximally thereof.  
26 The distal end of the inner member 260 terminates in a  
27 distal liquid orifice 285. A distal end 286 of the wire  
28 280 may also be tapered. The wire 280 is sized with  
29 respect to the inner tubular member 260 so that the  
30 tapered distal portion 286 of the wire 280 seats against  
31 the tapered distal portion 284 of the inner tubular  
32 member 260 and thereby seals a distal end of the liquid  
33 lumen 276 in a manner similar to a needle valve. The  
34 wire 280 is retractable and in a preferred embodiment is  
35 operated to reciprocate back and forth to pulse the  
36 delivery of liquid out the distal end of the nebulizing

1       catheter 252. The pulsing of aerosol delivery may be  
2       adjusted to any suitable time period. In one preferred  
3       mode of operation, the aerosol may be delivered only  
4       during inhalation by the patient. If the nebulizing  
5       catheter 252 is being used with an endotracheal tube and  
6       a ventilator, the pulsing of the aerosol delivery may be  
7       timed to coincide with the patient's inhalation by an  
8       appropriate connection with the ventilator. By limiting  
9       the delivery of medicine to only the period of time when  
10      the patient is inhaling, the medicine can be delivered  
11      more efficiently and with less waste.

12       One preferred way to generate the pulsed  
13      aerosol plume with the embodiment of FIGS. 18 and 19 is  
14      with a manifold arrangement 287. A proximal end of the  
15      wire 280 is fixed to an extendable section 288 of the  
16      manifold 287. The wire 280 may be fixed by means of an  
17      elastomeric seal 289. Pressurized gas is delivered to a  
18      port 290 of the manifold that communicates with the outer  
19      tubular member 256 and liquid medicine to be nebulized is  
20      delivered to a second port 291 that communicates with the  
21      inner tubular member 260. The liquid medicine also fills  
22      the volume 292 proximal of the port 291 in the expandable  
23      section 288. The wire 280 is connected to the manifold  
24      so that the distal end of the wire is biased against the  
25      distal end of the inner tubular member by the resilience  
26      of the inner tubular member 260 and/or the expandable  
27      section 288. Pulsed pressurization of the liquid  
28      medicine from the source causes the extendable section  
29      288 to reciprocate back and forth as shown by the arrow  
30      293. Since the proximal end of the wire 280 is attached  
31      to the expandable section 288 proximal of the port 291,  
32      application of pressure pulses to the liquid causes the  
33      proximal end of the wire 280 to reciprocate back and  
34      forth as well. This causes the distal end of the wire  
35      280 to reciprocate back and forth in the seat 284.  
36      Application of pressure pulses to the liquid medicine can  
37      be timed to coincide with the patient's inhalation.

1 Alternatively, instead of forming an expandable or  
2 compressible section at the manifold, the shaft of the  
3 inner tubular member 260 may be formed of a stretchable  
4 material so that pressurization of the liquid causes  
5 retraction of the wire as the entire shaft elongates.  
6 Other alternatives for effecting reciprocating operation  
7 of the wire 280 are use of an electro- mechanical,  
8 mechanical, hydraulic, or pneumatic actuator to drive the  
9 wire. Aside from providing for pulsed delivery of the  
10 aerosol, this embodiment of the nebulization catheter has  
11 the further advantage that the reciprocating action of  
12 the wire may assist in keeping the orifice free of any  
13 blockages which may occur, especially with some viscous  
14 solutions or suspensions.

15 In a manner similar to the embodiments 208 and  
16 236 of FIGS. 16 and 17, in the embodiment 252 of FIGS. 18  
17 and 19, the distal tip of the retractable wire 292 can  
18 extend distally from the distal liquid orifice 288 in  
19 order to minimize particle size, or alternatively may not  
20 extend distally of the distal liquid orifice 292. In one  
21 embodiment, the distal tip of the retractable wire may  
22 extend distally of the liquid orifice 288 by  
23 approximately .2 mm.

24 FIG. 20 shows another embodiment of a  
25 nebulizing catheter. In this embodiment, a nebulizing  
26 catheter 296 has a main shaft portion 300 with a gas  
27 lumen 304 adjacent to a liquid lumen 308. The gas and  
28 liquid lumens 304 and 308 flow into a distal cavity 312.  
29 The distal cavity 312 is formed by an outer tubular  
30 extension 316 that extends distally over and past a  
31 distal end 320 of the main shaft portion 300. A filter  
32 324 is located in the liquid lumen 308 to filter out any  
33 particles in the liquid. The liquid lumen 308 has a step  
34 down in diameter immediately distal of the location of  
35 the filter 324. An insert plug 328 is located in a  
36 distal end of the outer tubular extension 316. The

1 insert plug 328 (which may be a sapphire jewel, for  
2 example) has an aperture 332 through it that forms an  
3 exit orifice from the cavity 312. The insert plug 328  
4 has a conical shaped proximal profile facing the cavity  
5 312. An inner tubular extension 336 fits into the  
6 stepped down portion of the liquid lumen 308 and extends  
7 the liquid lumen 308 into the cavity 312. A distal end  
8 340 of the inner tubular extension 336 terminates in the  
9 cavity 312. Since the gas lumen 304 exits into the  
10 cavity 312, nebulization of the liquid takes place at the  
11 tip of the inner tubular extension 336 inside the cavity  
12 312. This region of the cavity 312 is a positive  
13 pressure region due to the relative sizes and locations  
14 of the apertures. The positive pressure in this region  
15 may have the effect of reducing drooling of the liquid  
16 medicine as it leaves the orifice of the tubular  
17 extension 336. The aerosol exits the catheter 296 via  
18 the aperture 332 and the aerosol plume is defined in part  
19 by the positive pressure in the cavity 312 and the  
20 aperture size. In this embodiment, the main shaft  
21 portion and the tubular extension are composed of a  
22 suitable plastic such as polyethylene. The filter is  
23 composed of multiple 50  $\mu\text{m}$  I.D. tubes or similar coarse  
24 filter material. The gas and liquid lumens may each have  
25 an I.D. of .010 to .015 inches. The inner tubular  
26 extension 336 may be formed of polyimide tubing with an  
27 I.D. of .004 inches and an O.D. of .010 inches. The  
28 outer tubular extension 316 may be formed of a heat  
29 shrunk tubing, such as polyethylene. The plug 328 may  
30 have an O.D. .087 inches and the aperture 332 in the plug  
31 328 may have a diameter of .007 inches.

32 FIG. 21 shows another embodiment of the  
33 nebulizing catheter. This embodiment is similar to the  
34 embodiment 296 shown in FIG. 20 and accordingly the  
35 components are numbered similarly. The embodiment of  
36 FIG. 21 differs from the embodiment of FIG. 20 in that

1 the distal end of the inner tubular extension 312 is  
2 located in the aperture 332 of the insert plug 328. In  
3 the embodiment of FIG. 21, the orifice 332 at the distal  
4 end of the tubular extension 336 is in a low pressure,  
5 high velocity region as compared to the embodiment of  
6 FIG. 20. This has a corresponding effect on plume size  
7 and shape as well as possible particle size.

8 FIG. 22 shows yet another embodiment for the  
9 nebulizing catheter. In this embodiment, a nebulizing  
10 catheter 340 has a main shaft portion 344 that has a gas  
11 lumen 348 and a liquid lumen 352. The gas lumen 348  
12 terminates distally in a gas orifice 356. Located in the  
13 distal end of the liquid lumen 352 is a liquid tubular  
14 extension 360. The liquid tubular extension 360 forms an  
15 angle so that a distal liquid orifice 364 is in alignment  
16 with the flow of gas out the distal gas orifice 356. In  
17 this embodiment, the liquid lumen 352 has an I.D. in the  
18 range of .010 to .020 inches. The gas lumen 348 has an  
19 I.D. of approximately 0.10 to .020 inches. The liquid  
20 tubular extension 360 is formed of a stainless steel tube  
21 with an O.D. of .018 inches and an I.D. of .012 inches.  
22 The distal gas orifice 356 has an I.D. of .010 inches.  
23 The stainless steel extension tube 360 forms a right  
24 angle so that the distal liquid orifice 364 is at a right  
25 angle and aligned with the distal gas orifice 356. The  
26 distal gas orifice 356 and the distal liquid orifice 364  
27 are positioned as close together as possible, and in one  
28 embodiment, these orifices are approximately .010 inches  
29 apart.

30 FIG. 23 shows an alternative embodiment of the  
31 nebulization catheter shown in FIG. 22. In this  
32 embodiment, the nebulization catheter 340 has an  
33 additional lumen 365. This additional lumen 365 may have  
34 an I.D. of approximately .020 inches. This additional  
35 lumen 365 may be used for an optical fiber viewing scope

1       366 for illumination and visualization of the distal end  
2       of the nebulization catheter 340. The optical viewing  
3       scope 366 may be permanently installed in the catheter  
4       340 or preferably may be removable. A distal end 367 of  
5       the lumen 365 is open or covered with a transparent lens  
6       so that the area distal of the catheter 340 can be  
7       observed via an optical viewing device connected to a  
8       proximal end of the optical fiber 366. This enables a  
9       physician to observe the alignment of the distal end of  
10      the nebulization catheter and also observe the  
11      nebulization when it occurs. The gas orifice 356 may be  
12      located so that the pressurized gas that is expelled  
13      helps to keep the distal end of the viewing lumen 365  
14      clear. An optical fiber viewing channel may be  
15      incorporated into any of the embodiments of the  
16      nebulization catheter disclosed herein. When the  
17      additional lumen 365 is occupied by a removable viewing  
18      scope, it may be used for other purposes such as pressure  
19      sensing, gas sampling, over pressure relief, or other  
20      diagnostic or therapeutic purposes. Alternatively,  
21      another lumen may be provided for these purposes.

22      The embodiment of FIG. 23 also shows opposing  
23      orifices. As in the embodiment of FIG. 22, a tubular  
24      extension 360 extends distally of the end of the catheter  
25      shaft and is oriented at an angle, e.g. 90 degrees, to  
26      the direction of the axis of the catheter shaft. The  
27      tubular extension 360 opens to a distal liquid orifice  
28      364 from which the liquid being conveyed in the lumen 352  
29      exits. In this embodiment, a second tubular extension  
30      363 communicates with the gas lumen 348 and opens to a  
31      distal gas orifice 367. The second tubular extension 363  
32      is also oriented relative to the axis of the catheter  
33      shaft, e.g. by 90 degrees, so that it is aimed toward the  
34      distal liquid orifice 364 in order to nebulize the liquid  
35      existing from the liquid orifice 367.

1 FIG. 24 shows still another embodiment of the  
2 nebulizing catheter. In this embodiment, a nebulizing  
3 catheter 368 has a main shaft section 372 with a gas  
4 lumen 376 and a liquid lumen 380. Tubular extensions 384  
5 and 388 extend the gas and liquid lumens 376 and 380 from  
6 the main shaft section 372 to a distal tip of the  
7 catheter 368. The distal portion of the shaft forms a  
8 tapered region 392 that surrounds the tubular extensions  
9 384 and 388 and causes them to be angled toward each  
10 other. The tubular extension 388 for the liquid lumen  
11 380 extends slightly distally of the distal end of the  
12 tubular extension 384 of the gas lumen 376 so that a  
13 distal liquid orifice 396 is in alignment with the flow  
14 of gas from a distal gas orifice 400. In this  
15 embodiment, the distal liquid orifice 396 has an O.D. of  
16 150 microns and an I.D. of 20 microns. The gas orifice  
17 400 has an I.D. of approximately .018 inches.

18 FIGS. 25 and 26 show an alternative embodiment  
19 of the nebulizing catheter 368 shown in FIG. 24. In  
20 FIGS. 25 and 26, the tubular extensions 384 and 388 of  
21 the gas lumen 376 and the liquid lumen 380 are formed  
22 with sealable tips. Specifically, the gas tubular  
23 extension 384 has a sealable tip 408 and the liquid  
24 tubular extension 388 has a sealable tip 412.  
25 Alternatively, only the liquid lumen 380 has the sealed  
26 tip 412 and the gas lumen 376 has an open distal orifice.  
27 The sealable tips may be formed by heating the material  
28 from which the tubular extensions are made to reform the  
29 walls of the plastic material so as to form a closed  
30 slit. This is represented in FIG. 26. When pressurized  
31 gas and liquid are conveyed through the lumens 376 and  
32 380, the slits forming the tips 408 and 412 dilate  
33 thereby permitting the gas and liquid to exit to from the  
34 aerosol, as illustrated in FIG. 25. However, when the  
35 pressure in the lumens 376 and 380 falls below a  
36 threshold, the tips 408 and 412 close thereby sealing off

1 the lumens, as illustrated in FIG. 26. The embodiment  
2 404 of the nebulizing catheter is used with pulsation of  
3 the gas and/or liquid supplies. In order to pulse the  
4 generation of aerosol to coincide with a patient's  
5 inhalation, the pressure to the gas and/or the liquid  
6 lumens can also be pulsed. When the pressure in either  
7 of the lumens falls below a threshold, the tips 408 or  
8 412 close. By closing off the flow of liquid at the tip  
9 412 during the period when the aerosol is not being  
10 generated, it is possible to reduce any drooling from the  
11 tip of the catheter.

12 **III. Nebulization With Counterflow**

13 As mentioned above, control of nebulized  
14 particle size and plume shape are important  
15 considerations affecting the efficacy of the therapy. In  
16 many applications, it is preferable to have as small a  
17 particle size as possible combined with as little forward  
18 velocity as possible. Some of the embodiments described  
19 below accomplish these objectives through use of  
20 counterflow arrangements.

21 FIG. 27 shows a nebulization catheter 416 that  
22 can be located inside of an endotracheal tube as in the  
23 previously described embodiments. The nebulization  
24 catheter 416 has a coaxial tubular arrangement with an  
25 outer tube 417 surrounding an inner tube 418 so that a  
26 liquid delivered from a distal liquid orifice 419 of the  
27 inner tube 418 is nebulized by the flow of a pressurized  
28 gas delivered in a distal direction from the annular  
29 region between the inner and outer tubes at the distal  
30 orifice 420 of the outer tube 417. In addition, another  
31 lumen 428 extends through the shaft of the nebulization  
32 catheter 416. This additional lumen 428 connects to a  
33 distal tubular extension 432. The tubular extension 432  
34 extends distally of the distal end of the nebulization  
35 catheter 416. A distal end 436 of the distal tubular  
36 extension 432 curves back on itself so that a distal

1 orifice 440 of the tubular extension 432 is oriented in a  
2 proximal direction back at the orifices 419 and 420 of  
3 the inner and outer tubes. The additional lumen 428 also  
4 carries a pressurized gas which is directed in a proximal  
5 direction by the orifice 440 against the direction of the  
6 aerosol plume generated by the gas and liquid exiting the  
7 orifices 419 and 420. The gas from the additional lumen  
8 428 presents a counterflow to the gas from these orifices  
9 thereby slowing down the velocity of the particles  
10 generated from these orifices. In a preferred  
11 embodiment, the distal tubular extension 432 may be  
12 formed of a suitable material such as stainless steel  
13 needle stock. The O.D. of the nebulization catheter in  
14 this embodiment may be similar to the other nebulization  
15 catheter embodiments described above, e.g. O.D of  
16 approximately .038 inches. The distal tubular extension  
17 432 may have an O.D. of approximately .013 inches and an  
18 I.D. of approximately .009 inches. In this embodiment,  
19 the outer tubular member of the nebulization catheter may  
20 have an O.D. of approximately .013 inches and an I.D. of  
21 approximately .009 inches and the inner tubular member  
22 may have an O.D. of approximately .003 inches and an I.D.  
23 of approximately .0015 inches.

24 FIG. 28 shows another embodiment of the present  
25 invention for a nebulizing catheter 448 that incorporates  
26 a counterflow arrangement. Like the embodiments  
27 described above, in this embodiment the nebulizing  
28 catheter 448 may be located in an endotracheal tube (not  
29 shown). The nebulization catheter 448 has a distal  
30 section 452 that curves back on itself. The nebulization  
31 catheter 448 has distal orifices 453 and 454 that  
32 generate a plume of nebulized particles in a reverse,  
33 i.e. proximal, direction. Also located in the  
34 nebulization catheter 448 is another lumen 456 for  
35 carrying a pressurized gas. The additional lumen 456 has  
36 a distal orifice 460 oriented in a distal direction. The

1       distal orifice 460 of the additional lumen 456 is aligned  
2       with respect to the distal orifices 452 and 453 of the  
3       nebulization catheter 448 so that the flow of gas from  
4       the additional lumen 456 slows down the velocity of the  
5       nebulization plume generated from the nebulization  
6       catheter 448. The aerosol plume generated by the  
7       nebulization catheter reverses direction and is delivered  
8       to the lungs carried by the inhalation of air through the  
9       endotracheal tube or by the flow of gas from the  
10      additional lumen 456 or a combination thereof.

11           FIGS. 29 and 30 show another embodiment of a  
12       counterflow nebulization catheter arrangement. In FIGS.  
13       29 and 30, a nebulizing catheter 464 is used with an  
14       endotracheal tube 468. A nebulization catheter 464 has a  
15       distal tip 472 from which a liquid medicine delivered  
16       from a distal liquid orifice is nebulized by a flow of  
17       pressurized gas from a gas orifice located adjacent to  
18       the liquid orifice. The nebulizing catheter 464 shown in  
19       FIG. 30 extends distally of the endotracheal tube 468 and  
20       has a distal section 476 that curves back on itself. The  
21       nebulization catheter 464 has distal orifices that  
22       generate a plume of nebulized particles in a reverse,  
23       i.e. proximal, direction back toward the distal opening  
24       of the endotracheal tube 464. In order to maintain a  
25       proper reverse orientation and to prevent snagging, the  
26       nebulization catheter 464 includes a wire 480 that  
27       extends from the tip 472 of the nebulization catheter  
28       464. The wire 480 is secured to a portion of the shaft  
29       of the nebulization catheter proximal of the tip. The  
30       wire 480 can be secured by means of a heat shrunk tube  
31       484 located on a shaft 488 of the catheter to hold the  
32       end of the wire 480. Although some aerosol may impact  
33       the wire 480, a wire having a small diameter is used to  
34       minimize losses due to such impaction. Moreover, the  
35       overall improved efficiency due to reduction in aerosol  
36       impaction on the walls of the trachea or other airway

1 passage is expected to more than compensate for any  
2 losses due to impaction on the wire 488.

3 In the embodiment shown in FIG. 30, the  
4 nebulization catheter 464 directs a nebulization plume in  
5 a reverse direction back toward the distal opening of the  
6 endotracheal tube 468. The nebulization plume from the  
7 nebulization catheter encounters the flow of air from the  
8 endotracheal tube 468 during the inhalation phase of the  
9 patient. The inhalation of air through the endotracheal  
10 tube 468 causes the nebulized medicine to reverse  
11 direction and carries it to the lungs. It is noted that  
12 the reversal of direction of the nebulization plume has  
13 the effect of minimizing the aerosol particle velocity.  
14 It is also noted in the embodiment shown in FIG. 30 that  
15 the endotracheal tube 468 is provided with an inflatable  
16 cuff 492 located around the distal portion.

17 **IV. Other Nebulization Catheter Embodiments**

18 In the embodiments described above, the  
19 velocity of the nebulization plume was reduced by use of  
20 a counterflow of gas in an opposite direction. In the  
21 embodiment of FIGS. 31 and 32, the velocity of the  
22 nebulization particles is reduced in another manner. In  
23 FIG. 31 a nebulization catheter 496 has a liquid lumen  
24 500 terminating in a distal liquid orifice 504 and a one  
25 or more gas lumens 508 terminating in one or more distal  
26 gas orifices 512. The liquid delivered through the  
27 liquid lumen 500 is nebulized by the pressurized gas  
28 flowing out the plurality of gas orifices 512. The  
29 nebulization catheter 496 also includes one or more  
30 additional lumens 516 that terminate in additional distal  
31 orifices 520. These lumens 516 are used to deliver a  
32 vacuum (negative pressure) at the distal orifices 520.  
33 The vacuum is provided by a suitable vacuum source (not  
34 shown) connected to proximal ends of the additional  
35 lumens 516. The vacuum delivered by the additional  
36 lumens 516 helps withdraw the pressurized gas delivered

1 by the lumen 508 after it has nebulized the liquid  
2 delivered by the liquid lumen 500. Without the vacuum  
3 provided by the additional lumens 516, the pressurized  
4 gas delivered by the distal gas orifices 512 may continue  
5 to impart energy to the nebulized liquid particles  
6 delivered by the distal liquid orifice 504 thereby  
7 causing them to be propelled with a forward velocity.  
8 Instead, the vacuum scavenges at least some of the  
9 pressurized gas after it has nebulized the liquid so that  
10 the forward velocity of the liquid particles can be  
11 reduced. In order to facilitate scavenging of the  
12 pressurized gas, the distal liquid orifice 504, the  
13 distal gas orifices 512, and the distal vacuum orifices  
14 520 all open into a distal cavity 524 formed by an outer  
15 tubular extension 528 of the nebulizing catheter 496.  
16 The distal extension 528 has a closed distal end 532 with  
17 a small aperture 536 located therein to emit the  
18 nebulized liquid particles with a low forward velocity.  
19 With the nebulizing gas removed, the aerosol particles  
20 are carried forward primarily only by their inertia.

21 The embodiment of the nebulization catheter 496  
22 shown in FIG. 31 includes a vacuum line 516 as a means to  
23 reduce the forward velocity of the nebulization plume.  
24 Provision of vacuum line 516 to the tip of a nebulization  
25 catheter 496 can serve an additional function of  
26 balancing the gas flow and pressure delivered to the  
27 airway in which the nebulization catheter is located.  
28 This may be useful to prevent excess airway pressure  
29 generated by the catheter flow particularly in smaller  
30 airways or where a neutral flow balance may be desired.  
31 This may particularly be desired when the nebulization  
32 catheter is provided with an inflatable cuff that  
33 occludes the airway passage at the distal end of the  
34 nebulization catheter. The flow balance may be  
35 controlled with a closed or partially closed pumping  
36 system where a gas pump 537 with a single intake and

1 outlet would be connected to the respective vacuum and  
2 gas supply lumens 516 and 508 of the catheter. Both the  
3 driving gas and vacuum would be balanced and regulated by  
4 the pump speed. A vacuum or pressure vent port 538 could  
5 be incorporated into the respective vacuum or pressure  
6 lines if a positive or negative flow balance was desired.  
7 If flow balance is a concern, but not velocity reduction,  
8 it is not important where the air flow is removed at the  
9 distal tip of the catheter and accordingly, the distal  
10 end extension 532 may not be needed. Alternatively, a  
11 flow balance may be maintained with separate a pressure  
12 and vacuum source through the use of regulators,  
13 restrictive capillary tubes or orifices, or flow sensors  
14 and flow control valves incorporated into the pressure  
15 and vacuum supply lines.

16 FIG. 33 shows another embodiment of a  
17 nebulization catheter 540 that incorporates a feature to  
18 reduce the forward velocity of the nebulized liquid  
19 particles. The nebulization catheter 540 has a main  
20 shaft portion 544 having a liquid lumen 548 and a  
21 pressurized gas lumen 552. The lumens 548 and 552  
22 terminate in distal orifices 556 and 560. The  
23 pressurized gas flow from the orifice 560 nebulizes the  
24 liquid exiting from the orifice 556. The nebulization  
25 catheter 540 includes a distal spacer tube 564. The  
26 spacer tube 564 has a length of approximately 2-3 mm and  
27 an inside diameter larger than the outside diameter of  
28 the nebulization catheter shaft 544. Because the inside  
29 diameter of the spacer tube 564 is larger than the  
30 airflow lumen and orifice, the velocity of air and  
31 entrained particles is reduced as they pass through the  
32 spacer tube 564 and out a distal opening 568 thereof.  
33 In addition, the spacer tube 564 may have one or more  
34 apertures or holes 572 through a wall thereof close to  
35 the proximal end of the spacer tube at its connection to  
36 the main shaft 544. These holes 572 draw in air to the

1       inside of the spacer tube 564 thereby causing drag due to  
2       turbulence and reducing the velocity of the aerosol as it  
3       exits the spacer tube. The holes 572 may also slow the  
4       flow of particles through the spacer tube by causing drag  
5       turbulence.

6       The spacer tube 564 also serves to protect the  
7       distal orifices 556 and 560 of the nebulization catheter  
8       from coming into contact with any part of the  
9       endotracheal tube, trachea, or other airway passage  
10      thereby helping to maintain optimum tip operation and to  
11      prevent damage to it during handling and insertion. In  
12      an alternative embodiment, if only the tip protection  
13      feature is desired, the spacer tube 564 of FIG. 33 may be  
14      provided without the apertures 572. In such an  
15      alternative embodiment, the spacer tube 564 may be  
16      provided in a shorter length, e.g. 1 mm.

17      FIG. 34 shows another embodiment of a  
18      nebulization catheter 576 used with an endotracheal tube  
19      580. The endotracheal tube 580 may be a conventional  
20      endotracheal tube. The nebulization catheter 576  
21      provides for a nebulization plume with a reduced forward  
22      velocity by imparting a spiral component to the liquid  
23      particle flow. The nebulization catheter 576 has a  
24      distal tip 584 from which a liquid medicine delivered  
25      from a distal liquid orifice is nebulized by a flow of  
26      pressurized gas from a gas orifice located adjacent to  
27      the liquid orifice. The nebulization catheter 576 is  
28      positioned coaxially in the endotracheal tube 580. A  
29      centering device 585 may be used to aid in centering the  
30      nebulization catheter 576. Located along a portion of  
31      the nebulization catheter 576 proximal from the tip 584  
32      is a second gas orifice 588. This second gas orifice 588  
33      may open to the same gas lumen that communicates with the  
34      nebulizing gas orifice at the distal tip 584 or  
35      alternatively, the second gas orifice 588 may connect to  
36      another, separate gas lumen. The second gas orifice 588

1 is oriented to direct a pressurized flow of gas in a  
2 spiral, distal direction along the distal end of the  
3 nebulization catheter 576. To accomplish this, the  
4 second gas orifice 588 may be formed by an inclined  
5 opening or with a deflection foil to direct the flow of  
6 gas in the appropriate spiral direction. The spiral flow  
7 of pressurized gas travels along the distal portion of  
8 the nebulizing catheter 576 inside the endotracheal tube  
9 580. The spiral flow of gas entrains the aerosol  
10 generated from the distal end 584 of the nebulizing  
11 catheter imparting a spiral flow component to the aerosol  
12 plume. This has the effect of reducing the forward  
13 velocity component of the liquid particle flow as it  
14 leaves the endotracheal tube 580.

15 FIG. 35 shows an alternative method for using  
16 the nebulization catheter 576 of FIG. 34. In FIG. 35,  
17 the nebulization catheter 576 is shown extended distally  
18 of the distal end of the endotracheal tube 580 so that  
19 the distal portion of the nebulization catheter 576  
20 including the second gas orifice 588 is located in an  
21 airway passage. Taking into account the size of the  
22 airway passage, the nebulization catheter 576 with the  
23 second gas orifice 588 would operate similarly to the  
24 method shown in FIG. 34 and generate a spiral gas flow to  
25 reduce the forward velocity of the aerosol plume.

26 Another embodiment of a nebulizing catheter 592  
27 is shown in FIGS. 36 and 37. This embodiment of the  
28 nebulizing catheter 592 can be used with a separate  
29 endotracheal tube (not shown). The nebulizing catheter  
30 592 includes a main shaft 596 having a central lumen 600  
31 and one or more additional lumens 604 located around the  
32 central lumen 600. In this embodiment, the central lumen  
33 600 is used for the flow of a pressurized gas and the  
34 additional peripheral lumens 604 are used for the  
35 delivery of the liquid medicine. The lumens 600 and 604

1 terminate distally in orifices 608 and 612, respectively.  
2 Located at a distal end of the nebulizing catheter 592  
3 and immediately adjacent the orifices 608 and 612 is a  
4 diffuser 616. In one embodiment, the diffuser 616 is  
5 composed of a generally disk-shaped body that is sized to  
6 deflect the flow of gas from the orifice 608 of the  
7 central lumen 600 past the liquid orifices 612 thereby  
8 nebulizing the liquid medicine. A small gap (or venturi  
9 area) 620 between the diffuser 616 and the distal end of  
10 the main shaft section 596 of the catheter 92 provides  
11 favorable flow characteristics for generating the  
12 aerosol. The diffuser 616 may be connected to a  
13 retaining wire 624 that is located in the central lumen  
14 600. The retaining wire 624 may be used to secure the  
15 diffuser 616 to the distal end of the nebulizing catheter  
16 592. Also, the retaining wire 624 may be used to pulse  
17 the generation of aerosol by reciprocation of the  
18 diffuser. It is noted that the aerosol produced by this  
19 embodiment has a substantially radial velocity component  
20 and may have only a small forward velocity component. In  
21 addition, a centering device, such as wings 625, may be  
22 attached to the diffuser 616.

23 FIG. 38 shows an alternative embodiment of the  
24 diffuser 616. In FIG. 38, the diffuser 616 is formed of  
25 a loop that has its ends located in two apertures in the  
26 nebulization catheter shaft tip and a middle portion  
27 directly in front of the distal gas orifice 608. The  
28 loop may be formed of a metal or polymer wire or other  
29 material. The loop could be formed by an extrusion  
30 method or molded.

31 Referring to FIG. 39, there is an alternative  
32 embodiment of the nebulization catheter system. A  
33 nebulization catheter 627 is located in an endotracheal  
34 tube 628. The nebulization catheter 627 includes a  
35 coaxially arranged outer tube 629, a middle tube 630, and

1 an inner tube 631. Liquid delivered through a lumen of  
2 the inner tube 631 is nebulized by pressurized gas  
3 delivered in the annular region 632 between the inner  
4 tube 631 and the middle tube 630. In addition,  
5 pressurized gas is also delivered from a secondary gas  
6 supply that communicates with the annular region 633  
7 between the middle tube 630 and the outer tube 629. The  
8 secondary gas supply may be used to help provide the  
9 desired plume shape and velocity. For example, the  
10 secondary gas supply delivered from the outer tube 629  
11 can be used to provide a coaxial sheath of air that helps  
12 minimize impaction of the nebulized aerosol on the walls  
13 of the trachea or other airway passage. Alternatively,  
14 the secondary air supply may be used to impart additional  
15 forward velocity to the aerosol plume. With the  
16 embodiment of FIG. 39, the additional air flow can be  
17 provided by the secondary gas supply via region 633.

18 In the embodiments discussed above,  
19 nebulization is provided at a distal tip of a catheter by  
20 directing a pressurized gas from a distal orifice across  
21 another distal orifice from which the liquid medicine is  
22 delivered. As shown in several of the embodiments above,  
23 one way to deliver the liquid from the distal orifice is  
24 via a lumen that extends through the catheter to a  
25 proximal end. This construction provides efficient  
26 operation for many types of medication delivery. In many  
27 cases, the distal liquid medicine orifice is subject to a  
28 negative pressure due to the pressurized gas flow across  
29 it. This negative pressure may in many applications be  
30 sufficient to draw the liquid out of the orifice in order  
31 to nebulize it. If pulsing of the aerosol is desired,  
32 the pressure of the gas lumen can be pulsed thereby  
33 resulting in pulsed generation of the aerosol. By  
34 increasing the gas pressure, it may be possible to also  
35 increase the aerosol output.

1           In other situations, it may be preferable to  
2   apply a positive pressure to the liquid, such as at the  
3   proximal end of the liquid lumen, in order to deliver  
4   liquid from the distal liquid orifice, it is necessary.  
5   This positive pressure applied to the liquid lumen may be  
6   the same as that applied to the gas lumen (e.g. 35-50  
7   psi) or alternatively may be different (less than the gas  
8   lumen). If it is desired to pulse the nebulization of  
9   the liquid, this can be accomplished by applying pulses  
10   of pressure to the column of liquid via the proximal end  
11   of the liquid lumen or reservoir. It may also be  
12   preferred to synchronize the pressurization of the gas in  
13   the gas lumen with the pressurization of the liquid  
14   lumen. In addition to applying the positive pressure to  
15   the liquid lumen in pulses to generate a pulsed aerosol  
16   from the distal orifice, if it may be preferred in an  
17   alternative embodiment to apply a small negative pressure  
18   immediately after each positive pressure pulse in order  
19   to draw the liquid at the distal orifice back into the  
20   liquid lumen to thereby avoid drooling. In a preferred  
21   embodiment, the portion of the nebulization catheter in  
22   which the liquid lumen is formed may be composed of a  
23   relatively low compliance material to transmit pressure  
24   pulses to the distal end with minimum attenuation.

25           A full length liquid lumen may have  
26   disadvantages in certain situations. For example,  
27   pulsing of the liquid from the distal orifice may not  
28   correspond to or follow closely with the application of  
29   pressure to the proximal end due to attenuation of the  
30   pressure pulse over the length of the catheter. In  
31   addition, applying pressure to the proximal end of the  
32   liquid lumen in order to transmit pressure to discharge  
33   the liquid from a distal orifice requires that the lumen  
34   be filled with the liquid. In some situations, this is  
35   more medicine than would be required by the patient and  
36   might result in waste.

1           The embodiment in FIG. 40 addresses these  
2   concerns by controlling the pressurization of the liquid  
3   as close as possible to the distal liquid orifice,  
4   thereby reducing the effects of catheter compliance and  
5   attenuation. In FIG. 40, a nebulization catheter 652 has  
6   a main body 656 having a gas lumen 660 that extends from  
7   a proximal end (not shown) to a distal gas orifice 664.  
8   The main body 656 also includes a distal liquid medicine  
9   reservoir 668. In the embodiment shown in FIG. 40, the  
10   liquid reservoir 668 is located in a distal portion of  
11   the main shaft 656 of the catheter 652. The liquid  
12   reservoir 668 is preferably close to the distal tip of  
13   the nebulizing catheter 652. The liquid reservoir 668 is  
14   filled with the medicine to be delivered. If the amount  
15   of medicine is small in volume, the liquid reservoir may  
16   also be correspondingly small. This embodiment is  
17   especially suitable for the delivery of small volumes of  
18   medicine such as .1 to .5 ml, e.g. single use. The  
19   reservoir 668 may be pre-filled during the manufacturing  
20   stage of the catheter. The reservoir 668 may be formed  
21   by plugging a lumen of the catheter at a distal location.  
22   Alternatively, the liquid reservoir 668 may also extend  
23   back to the proximal end of the catheter, thereby forming  
24   a liquid lumen, and communicate with a proximal port as  
25   described with respect to the other embodiments discussed  
26   herein. This may be required if the lumen is made of a  
27   non-compliant material. In yet another alternative  
28   embodiment, the liquid reservoir may be formed in a  
29   balloon located externally of the catheter shaft 656.

30           A filter 672 and plug 676 occupy positions in  
31   the distal end of the liquid lumen/reservoir 668. A  
32   distal tubular extension 680 extends from the plug 676  
33   and communicates with the liquid lumen/reservoir 668.  
34   The tubular extension 680 has a distal orifice 684  
35   aligned with the distal gas orifice 664 so that a  
36   pressurized gas exiting the gas orifice 664 nebulizes the  
37   liquid exiting the liquid orifice 684. The distal liquid

1 orifice may have a sealable cap or wax-like covering  
2 associated therewith that can be opened when the  
3 nebulization catheter is put into use. In a distal  
4 section of the main shaft 656 of the catheter 652, the  
5 gas lumen 660 and the liquid lumen 668 are separated by a  
6 flexible, distendable wall or membrane 688. In the  
7 embodiment of FIG. 40, pulsing of the aerosol is  
8 accomplished by pulsing of the gas pressure in the gas  
9 lumen 660. When the pressure in the gas lumen 660 is  
10 high, it causes the flexible wall 688 between the gas and  
11 liquids lumens 660 and 668 to distend into the liquid  
12 lumen 668. This is represented by the dashed line in  
13 FIG. 40. When this occurs, the pressure from the gas  
14 lumen 660 is transmitted to the liquid lumen 668 and  
15 liquid medicine is forced out the distal liquid orifice  
16 684. When the pressure applied to the gas lumen 660 is  
17 low, the distendable wall 688 recovers its original  
18 position. It is noted that when the distendable wall 680  
19 recovers its original position, it may cause a negative  
20 pressure at the distal liquid orifice 684 which may cause  
21 the liquid to withdraw slightly into the tubular  
22 extension 680 thereby reducing the occurrence of liquid  
23 drooling at the tip. In addition, it is noted that the  
24 delivery of liquid from the distal liquid orifice 680 may  
25 not occur immediately upon application of a high gas  
26 pressure to the gas orifice since it will take some time  
27 for the bladder 688 to distend. This means that gas will  
28 be flowing steadily at a high pressure from the distal  
29 gas orifice when the liquid begins to flow from the  
30 distal liquid orifice. This also may provide cleaner  
31 aerosol delivery and reduce the occurrence of drooling of  
32 liquid at the tip.

33 An alternative embodiment of the nebulization  
34 catheter 652 shown in FIG. 40 may be made using a  
35 flexible, but inelastic material for the bladder wall  
36 688. If the bladder wall 688 were flexible, but  
37 inelastic, the pressurized gas passing past the liquid

1 orifice 684 would create a negative pressure (venturi  
2 effect) thereby drawing out the liquid and nebulizing it.  
3 A continuous or preferably an intermittent gas supply to  
4 the venturi area would provide this negative pressure.  
5 The bladder wall may be provided with a vent to  
6 facilitate discharge.

7 In order to manufacture a nebulization catheter  
8 with compliant and non-compliant regions, as described  
9 above, the catheter may be co-extruded using different  
10 compounds or polymers to optimize the physical properties  
11 of the different wall sections. It may be preferred to  
12 use high energy radiation to crosslink the polymer  
13 material in the formation of the bladder wall.

14 V. Alignment of the Aerosol Plume

15 The embodiments described above are directed to  
16 developing an optimum nebulization plume. It is further  
17 recognized that another factor that contributes to the  
18 efficiency of the nebulization is the position of the  
19 nebulization catheter relative to the anatomical  
20 environment. For example, even if the nebulization  
21 catheter being used develops an optimal plume, the  
22 delivery efficiency of the catheter may be significantly  
23 impaired if the plume is directed into the wall of the  
24 endotracheal tube, the trachea or other airway passage.  
25 Accordingly, proper location, orientation, and alignment  
26 of the nebulization catheter in the anatomy can be an  
27 important factor contributing the delivery of medicine  
28 via a nebulization catheter. In general, it is  
29 preferable to align the catheter coaxially in the airway  
30 passage in which it is located.

31 It is also noted that an endotracheal tube, if  
32 present, can adversely effect delivery of aerosol from a  
33 separate nebulization catheter. For example, an  
34 endotracheal tube has an inner diameter that is smaller  
35 than the diameter of the trachea so that if the  
36 nebulization takes place inside the endotracheal tube, a

1 portion of the aerosol may impact the inner wall of the  
2 endotracheal tube and thereby be wasted. Most  
3 conventional endotracheal tubes have a curved distal end  
4 that is relatively rigid so that when it is in place in  
5 the trachea of a patient, the distal end of the  
6 endotracheal tube is oriented off center. This can  
7 affect the orientation of a nebulization catheter located  
8 in the endotracheal tube causing it direct its aerosol  
9 into the trachea wall even if the nebulization catheter  
10 is positioned so that its distal end is located distally  
11 of the endotracheal tube. In general, it is desirable to  
12 allow the aerosol particles to avoid impaction for  
13 several centimeters after the aerosol is produced so that  
14 the aerosol particles can lose their velocity and become  
15 entrained in the inspiratory airflow.

16 The embodiment of the invention in FIG. 41 is  
17 directed at providing improved alignment of a  
18 nebulization catheter in a patient's trachea. In FIG.  
19 41, an endotracheal tube 700 is positioned in a trachea  
20 704 of a patient. The endotracheal tube 700 is of a type  
21 that has an inflatable cuff 708 located around a distal  
22 exterior side to facilitate positioning and alignment of  
23 the endotracheal tube 700 in the trachea 696. Extending  
24 through and out of a distal end of the endotracheal tube  
25 700 is a nebulization catheter 712. The nebulization  
26 catheter 712 may be similar to any of the embodiments of  
27 the nebulization catheter described above. Located  
28 around a distal portion 716 of the nebulization catheter  
29 712 is a spring centering apparatus 720. The spring  
30 centering apparatus 720 includes a retainer ring 724  
31 fixed to the shaft of the nebulization catheter 712 and a  
32 plurality of arms 728 connected to the ring 724. In one  
33 embodiment, there are three arms 726. The arms 726 are  
34 flexible and resilient. The arms 726 may be made of a  
35 spring tempered metal or a suitable plastic. Located at  
36 the end of each of the arms 726 opposite its connection  
37 to the ring 724 is a ball 727. The spring centering

1 apparatus 720 is deployed by first positioning the  
2 nebulizing catheter 712 including the spring centering  
3 apparatus in the lumen 728 of the endotracheal tube 700.  
4 The arms 726 are formed so that they assume a size larger  
5 than the diameter of the trachea or airway passage.  
6 Accordingly, when the centering device is positioned in  
7 the endotracheal tube 700, the arms are resiliently  
8 deformed into a compressed configuration with the balls  
9 727 close to the shaft of the nebulizing catheter 712.  
10 To deploy the centering device, the nebulizing catheter  
11 712 is advanced out the distal end of the endotracheal  
12 tube 700. When the balls 727 are advanced out the  
13 endotracheal tube 700, they spring out to an expanded  
14 size and engage the walls of the trachea or other airway  
15 passage. The balls 727 provide a relatively smooth  
16 surface to limit irritation or injury to the trachea  
17 walls or other airway passage. With the arms expanded,  
18 the nebulizing catheter is centered in the trachea or  
19 other airway passage so that a plume discharged from a  
20 distal end of the nebulizing catheter has minimal contact  
21 with the walls of the trachea or other airway passage.  
22 When it is necessary to remove the nebulizing catheter  
23 712, it can be withdrawn in a proximal direction back  
24 into the endotracheal tube 700. In a preferred  
25 embodiment, the arms are formed of a thin resilient wire  
26 or polymer, preferably less than approximately .015  
27 inches in diameter. The arms and/or the balls may be  
28 made of, or coated with, a radiopaque material. It is an  
29 advantage of the embodiment of the centering device shown  
30 in FIG. 41 that it is located somewhat in advance of the  
31 distal end of the nebulization catheter. This positions  
32 the arms 726 of the centering device in the portion of  
33 the trachea or other airway passage into which the  
34 aerosol will be initially flowing. Thus, the centering  
35 device orients the distal tip of the nebulization  
36 catheter relative to the portion of the trachea or other

1 airway passage beyond the distal tip thereby helping to  
2 reduce impaction along this portion.

3 FIG. 42 shows an alternative embodiment of the  
4 nebulization catheter. A nebulization catheter 729 is  
5 used with an endotracheal tube as described above. The  
6 nebulization catheter 729 includes a centering device  
7 730. The centering device 730 includes a plurality of  
8 arms 731 that are formed to resiliently extend outward  
9 from the axis of the catheter shaft to engage the wall of  
10 the patient's trachea or airway passage or the interior  
11 of an endotracheal tube depending upon the desired  
12 location of the distal end of the nebulization catheter.  
13 At the ends of each of the arms 731 are balls 732. The  
14 proximal ends of the arms 731 are formed of wires 733  
15 that extend through lumens 734 in the shaft of the  
16 catheter 729. Each of the lumens 734 has a distal  
17 opening 735 from which an arm can extend. The distal  
18 openings are approximately .10 - 1 cm from the distal end  
19 of the catheter shaft. The proximal ends of the wires  
20 733 exit the lumens 734 of the nebulization catheter via  
21 openings 736 that are close to the proximal end of the  
22 catheter in a portion of the catheter that would normally  
23 be outside the patient's body during use. Thus, the  
24 proximal ends of the wires 733 are accessible to the  
25 physician during use. By pulling and pushing on the  
26 proximal ends of the wires 733, the portion of the arms  
27 731 that extend from the openings 735 can be adjusted.  
28 Thus, the arms 731 can be adjusted from a fully retracted  
29 to a fully advanced position by pulling or pushing on the  
30 proximal ends of the wires 733. In addition, since the  
31 proximal ends of the wires 733 can be adjusted in any  
32 intermediate position between the fully retracted and  
33 fully advanced positions, the physician can adjust the  
34 size of the centering device 730 to any appropriate size,  
35 as desired. Because the wires 733 should assume a  
36 desired shape when advanced out of the lumens in which  
37 they are contained during positioning, it is preferable

1 that they be formed of a material that has shape memory  
2 properties so that the desired expanded shape can be  
3 imparted to the wires during manufacture. In one  
4 embodiment, the wires may be formed of nitinol.

5 In one preferred embodiment, a second centering  
6 device 737 is also provided. The second centering device  
7 737 is located on the shaft of the nebulization catheter  
8 729 proximally from the first centering device 730. The  
9 second centering device 737 may be formed of resilient  
10 wings formed of a material such as plastic or metal that  
11 extend radially outward from the shaft. The second (or  
12 proximal) centering device 737 helps keep the distal  
13 portion of the catheter 729 in alignment.

14 FIG. 43 shows another alternative embodiment of  
15 the present invention. A nebulizing catheter 738 is  
16 shown which may be similar to the catheter 20 of FIG. 1.  
17 The nebulizing catheter 738 includes a centering device  
18 739. The centering device 739 includes a wire loop 740  
19 located at a distal end of the catheter. One end 741 of  
20 the loop 740 connects to the distal end of the nebulizing  
21 catheter shaft. The other end 742 of the wire loop 740  
22 enters an opening 743 in the shaft that communicates with  
23 a lumen 744 that extends to a proximal end of the  
24 catheter 738. A proximal end 745 of the wire exits the  
25 lumen 744 via an opening 746 in a proximal portion of the  
26 nebulizing catheter which is normally outside the  
27 patient's body during use. The size of the wire loop 740  
28 can be adjusted by advancing or withdrawing the proximal  
29 end 745 of the wire. In this embodiment, it can be  
30 determined that the centering device is fully retracted  
31 when the wire 745 cannot be withdrawn any further. The  
32 position of the distal end of the nebulization catheter  
33 can also be determined by the resistance to further  
34 retraction caused when the loops or arms engage the  
35 distal end of the endotracheal tube. When in an expanded  
36 size, the wire loop 740 engages the walls of the trachea

1 or airway passage or the interior of the endotracheal  
2 tube depending upon where the distal end of the  
3 nebulizing catheter is positioned. The size of the wire  
4 loop 740 can be adjusted from a fully reduced size to a  
5 fully expanded size as well as intermediate sizes. With  
6 the embodiment of FIG. 43, the size of the loop can be  
7 adjusted to different size airway passages in different  
8 patients or alternatively the size of the loops can be  
9 adjusted to different airway passages in the same patient  
10 if the physician desires relocating the nebulizing  
11 catheter to different locations in a patient's  
12 respiratory tract. In a one preferred embodiment, more  
13 than one wire loop may be provided at the distal end of  
14 the nebulizing catheter. It is noted that the wire loop  
15 740 of this embodiment may also be used in for  
16 facilitating positioning over a guide wire in a manner  
17 similar to loop 106 shown in FIG. 9.

18 FIGS. 44 and 45 show another alternative  
19 embodiment of the present invention. A nebulizing  
20 catheter 747 has a shaft portion 748 and a wire loop 749  
21 extending from a distal end of the shaft 748. In this  
22 embodiment, the wire loop 749 is connected at each end  
23 750 and 751 to the distal end of the catheter shaft 748.  
24 A retractable sheath 752 is positioned over the  
25 nebulizing catheter shaft 748. The sheath 752 can be  
26 advanced and withdrawn relative to the catheter shaft  
27 748. When it is desired to maneuver the nebulizing  
28 catheter into a desired position in the respiratory tract  
29 of a patient, the sheath 752 is advanced over the loop  
30 749 to maintain a low profile, as shown in FIG. 45. When  
31 the distal end of the nebulizing catheter is suitably  
32 positioned, the sheath 752 is then retracted, as shown in  
33 FIG. 44, allowing the loop 749 to expand to its expanded  
34 size to center and align the distal end of the nebulizing  
35 catheter in the respiratory tract. In one embodiment,

1 the loop 749 is formed of a superelastic material such as  
2 nitinol.

3 As noted above, proper positioning and  
4 alignment of the nebulization catheter can be an  
5 important factor affecting drug delivery efficiency. In  
6 general, it is preferable to position the tip of the  
7 nebulizing catheter as closely to the central region of  
8 the trachea (or other respiratory passage, such as the  
9 bronchi) as possible. It is further noted that even if  
10 the catheter can be centered relative to the trachea, if  
11 a section proximal to a centering device is misaligned,  
12 it can affect the directional orientation of the tip.  
13 This situation is represented in FIG. 46 in which a  
14 nebulizing catheter 753 is centered, but the tip is not  
15 properly aimed to provide an optimum plume. This  
16 potential problem can be overcome by using an embodiment  
17 of the invention shown in FIG. 47. In FIG. 47, a  
18 nebulizing catheter 754 is located in a trachea 755 of a  
19 patient. The nebulizing catheter 754 extends out the end  
20 of an endotracheal tube 756. A first centering apparatus  
21 757 is located on a main shaft 760 of the nebulizing  
22 catheter 754 close to the distal end 764. The first  
23 centering device 757 may be similar to the centering  
24 devices shown in FIGS. 41 - 45. A second centering  
25 device 768 is located axially along the nebulizing  
26 catheter shaft 760 proximally from the first centering  
27 device 757. The second centering device 768 may be the  
28 same as the first centering device 757. As shown in FIG.  
29 47, the two centering devices 757 and 768 not only serve  
30 to position the nebulization catheter 7754 centrally in  
31 the trachea, but also serve to align the nebulizing  
32 catheter tip to expel the plume along a central axis of  
33 the trachea.

34 The proximal centering device 768 may be  
35 substituted by another type of centering device or may  
36 employ the endotracheal tube 756 for this purpose, as  
37 shown in FIG. 48. If the endotracheal tube is used to

1 assist in centering the nebulization catheter, it may  
2 incorporate a distal, elongated occlusion cuff 772 or  
3 balloon to coaxially align it accurately in the trachea.  
4 Most conventional endotracheal tubes are provided with a  
5 curvature to facilitate positioning the trachea of a  
6 patient. In addition, most conventional endotracheal  
7 tubes are relatively stiff. These factors may result in  
8 the misalignment of the distal end of the endotracheal  
9 tube relative to a patient's trachea as illustrated in  
10 FIGS. 46 and 47. In order to use the endotracheal tube  
11 for centering of the nebulization catheter, it is  
12 preferable to make the tip of the endotracheal tube  
13 straighter and/or more flexible than in conventional  
14 endotracheal tubes to ensure proper concentricity with  
15 the occlusion balloon and the trachea. An endotracheal  
16 tube with a straighter and more flexible tip is shown in  
17 FIG. 48. In addition, the endotracheal tube may be  
18 provided with a centering or aiming device 776 for  
19 aligning the nebulization catheter 754. In the  
20 embodiment of FIG. 48, the aiming device 776 is formed by  
21 a plurality of flexible or resilient wings that extend  
22 from the wall of the endotracheal tube 756 toward an  
23 axially central position.

24 Appropriate centering and aiming of the  
25 nebulization catheter can be affected by anatomical  
26 factors. It is noted that in some circumstances, it is  
27 preferable to position the distal tip of the nebulization  
28 catheter into either bronchus of the lungs or even into  
29 separate bronchia. Positioning of the nebulizing tip  
30 closer to the alveoli may enhance drug delivery  
31 efficiency. In a situation in which it is desired to  
32 place the nebulizer tip in both bronchi of the lungs, a  
33 nebulizing catheter 780 with dual tips can be employed,  
34 as shown in FIG. 49. When using a dual tip catheter such  
35 as shown in FIG. 49, centering and aiming can be  
36 important considerations because of the narrower air  
37 passages in each of the bronchi. To provide for

1 centering and aiming of a dual tip nebulizing catheter,  
2 each of the tips 784 and 788 may be provided with its own  
3 centering apparatus, such as 792 and 796. These  
4 centering devices may be similar to the centering devices  
5 described above. Alternatively, the centering devices  
6 792 and 796 may be formed of arms or struts, made of a  
7 flexible or resilient material, that bow out from the  
8 shafts of each of the tips 784 and 788, as shown. These  
9 struts may be formed with a shorter length in order to  
10 fit into smaller airway passages or alternatively they  
11 may be made to provide a range of deployment sizes to  
12 accommodate different airway passages.

13 As an alternative to providing a nebulizing  
14 catheter with dual tips 784 and 788 as shown in FIG. 49,  
15 if delivery of aerosolized medicine into separate  
16 branches of the lungs is desired, it may be preferred to  
17 use a nebulizing catheter with a single nozzle tip that  
18 has multiple orifices or jets aimed toward the desired  
19 branches.

20 With respect to all the centering devices  
21 described above, it is noted that some aerosol may impact  
22 the wires or loops that form the centering devices and  
23 accordingly, the centering devices are preferably  
24 constructed of wires or other materials having a small  
25 diameter or cross section to minimize losses due to such  
26 impaction. Moreover, the overall improved efficiency due  
27 to the reduction in aerosol impaction on the walls of the  
28 trachea or other airway passage is expected to more than  
29 compensate for any losses due to impaction on the  
30 centering device.

31 Another alternative means for centering the  
32 distal end of a nebulization catheter in the air passage  
33 is to use part of the pressurized gas for a pneumatic  
34 centering device. Air jets generated from two or more  
35 outward directed orifices spaced evenly around the outer  
36 circumference of the nebulizing catheter near the tip can  
37 be used to center the catheter in the airway. This

1       alternative may help avoid irritation and provide  
2       additional advantages compared to physical centering  
3       devices.

4           Another alternative way to help center the  
5       nebulizing catheter in the patient's airway passage is to  
6       use a balloon or wire centering device placed near the  
7       nebulizing catheter tip. The balloon or wire centering  
8       device can be temporarily inflated to double check the  
9       placement of the nebulizing catheter tip in relation to  
10       the endotracheal tube tip. To use this feature the  
11       nebulizing catheter is advanced beyond the endotracheal  
12       tube tip using markings on the proximal shaft to judge  
13       the distance. The centering device or balloon would then  
14       be expanded to a diameter larger than the endotracheal  
15       tube and the catheter retracted until the centering  
16       device or balloon could be felt engaging with the  
17       endotracheal tube tip or until the endotracheal airflow  
18       was obstructed.

19       VI. Operation and Flow Control

20           As mentioned above, the driving gas used to  
21       pressurize the gas lumen may be pure (e.g. 100%) oxygen  
22       at a pressure of 35-50 psi. Other gases and pressures  
23       may be used with suitable adjustments to provide for the  
24       desired particle size. The pressurized gas also may be  
25       humidified by a bubbler or other suitable means and  
26       warmed, if necessary.

27           Regarding the liquid lumen, one way to deliver  
28       the liquid drug through the nebulizing catheter is by a  
29       manually operated syringe. To delivery a liquid drug in  
30       this manner, a syringe containing the liquid medicine to  
31       be nebulized is connected to the liquid port on the  
32       manifold connected to a proximal end of the nebulizing  
33       catheter. Then, the liquid is injected while the  
34       pressuring gas is being supplied to the nebulizing  
35       catheter via the gas inlet port on the nebulizing  
36       catheter manifold. Using a manually operated syringe is

1 reliable, easy to use, and may be preferred when it is  
2 desired to deliver only a small amount of medication.

3 In a preferred embodiment, the liquid drug is  
4 delivered to the nebulizing catheter from a pressurized  
5 source. A pressurized source for the liquid medicine can  
6 provide for a generally higher and more uniform pressure.  
7 A high pressure assists in clearing any blockages that  
8 may occlude the liquid lumen. Pressurization of the  
9 liquid lumen also can ensure that all the liquid drug is  
10 evacuated from the catheter tip. In addition, use of a  
11 liquid pressurization source can provide for drug  
12 delivery for a longer period of time or a drug delivery  
13 that is timed or pulsed to coincide with operation of a  
14 ventilator, if used. In a preferred embodiment, the same  
15 pressure source (at 50 psi) that is used to provide the  
16 gas pressurization can also be used to provide for  
17 pressurization of the liquid. Some ventilators have an  
18 auxiliary port that are used for externally located  
19 nebulizers. The pressure flow from this auxiliary port  
20 may be used as a pressure source to drive the liquid and  
21 gas supplies of the embodiments of the nebulizing  
22 catheter considered herein. Alternatively, a sensor  
23 located in the flow from this auxiliary port may be used  
24 to trigger another control device that operates the  
25 pressurized liquid and gas supplies.

26 In a preferred embodiment, the generation of  
27 the aerosol can be synchronized with the inhalation of  
28 the patient. In one embodiment, this can be accomplished  
29 with a manually operable control gas valve on the gas  
30 pressure line to the liquid input port. This may be  
31 suitable when the medicine can be delivered in a short  
32 period of time, e.g. a few respiratory cycles.  
33 Alternatively, when it is preferred to deliver the  
34 medicine for an extended period of time, it may be  
35 preferred to employ a system that can automatically  
36 deliver medicine via the nebulizer from a source of  
37 liquid medicine. In such a system, the gas and/or liquid

1 flow are triggered by the patient's respiratory cycle  
2 with the use of an electronic pressure sensor and relay  
3 actuator.

4 An important factor relating to effective  
5 delivery of medication via a nebulizing catheter is the  
6 flow control system for pressurizing and supplying the  
7 gas and liquid to the proximal end of the nebulization  
8 catheter. In many circumstances, it is envisioned that  
9 medication will be delivered to the patient via a  
10 nebulization catheter that is in place in the patient  
11 over an extended period of time, such as several hours or  
12 days. In such circumstances, it would be preferred to  
13 use a system that automatically delivers the proper  
14 dosage of medication from a supply of the medicine to the  
15 patient at the proper rate, and further that can operate  
16 automatically and unattended. Further, it would be  
17 preferred to provide a means to detect when the supply is  
18 running low so that either the nebulization catheter can  
19 be disconnected or a new supply provided. FIGS. 50 and  
20 51 show several embodiments of a reservoir and  
21 pressurization system for use with a nebulizing catheter.

22 Referring to FIG. 50, a reservoir and  
23 pressurization assembly 800 is connected to a proximal  
24 end of a nebulization catheter. The nebulization  
25 catheter may be similar to any of the embodiments  
26 described above. The assembly 800 has a gas inlet port  
27 804 that can connect to an external pressurized gas  
28 supply. The external pressurized gas supply may be the  
29 main gas supply of the hospital or may be provided by  
30 another unit. The external gas supply may provide oxygen  
31 at 50 psi. The gas inlet port 804 communicates with an  
32 airflow passageway 808 defined by and extending through  
33 the assembly 800. The assembly 800 includes a gas output  
34 port 812 that communicates with the fluid flow passageway  
35 808 and which connects to a gas inlet port of the  
36 nebulization catheter (not shown). The gas output port  
37 812 is located immediately downstream of the gas inlet

1 port 804. Located in the fluid flow passageway 808  
2 downstream of the gas outlet port 812 is a filter 816.  
3 The filter 816 is preferably a hydrophobic filter that  
4 allows the passage of gas but which would prevent the  
5 backflow of any liquid. Located downstream of the filter  
6 816 in the fluid flow passageway 808 is an injection port  
7 and reservoir 820. This port 820 communicates with a  
8 supply of the liquid fluid medication to be supplied to  
9 the nebulizing catheter. Located next in the fluid flow  
10 passageway 808 is a capillary tube drug reservoir 824.  
11 The capillary tube reservoir 824 is comprised of a length  
12 of plastic tubing adapted to hold a supply of the liquid  
13 medication to be delivered. In the embodiment shown, the  
14 capillary tube reservoir consists of a helical coil of  
15 transparent tubing. Located downstream of the capillary  
16 tubing reservoir 824 is a liquid outlet 828 that connects  
17 to a liquid inlet port of the nebulization catheter (not  
18 shown). With the embodiment shown in FIG. 50, the  
19 transparent capillary tubing 824 provides a convenient  
20 and reliable way to ascertain the supply of medication to  
21 the nebulizing catheter. The capillary tubing because of  
22 its length is capable of containing a suitable supply of  
23 the medication. When the attending medical personnel  
24 observe that the medication is about to run out, a new  
25 supply can be readily provided. The clear capillary tube  
26 allows easy visualization of the drug flow by watching  
27 the gas-drug meniscus travel down the tube. Instead of  
28 relying on direct observation by medical personnel, the  
29 capillary tubing may be used with an automatic detection  
30 device, e.g. a photocell, that provides an alarm to the  
31 medical personnel upon detection that the medication is  
32 running out in the capillary tubing or that the meniscus  
33 has ceased moving due to a blockage. A blockage may also  
34 be detected by detection of an increase in pressure.

35 FIGS. 51 and 52 show another embodiment of a  
36 fluid reservoir and pressurization assembly 832. This

1 embodiment includes a gas inlet 836, a fluid flow  
2 passageway 840, a liquid medicine supply vent 844, a  
3 filter 848, a capillary channel section 852, and an  
4 outlet port 856. In this embodiment, the filter 848 is  
5 located downstream of the filling vent 844. The filter  
6 848 allows the pressurized gas to push the liquid drug  
7 during use but prevents the liquid drug from backing up  
8 to the vent during filling. In this embodiment, a second  
9 injection port 860 is provided downstream of the  
10 capillary section 852 and a second filter 864 is located  
11 downstream of the second injection port 860. The second  
12 filter 864 is preferably a filter having approximately a  
13 20  $\mu\text{m}$  retention. Also, in this embodiment, the capillary  
14 section 852 may be composed of a planar section 865. The  
15 planar section 865 may be a piece of plastic having a  
16 winding channel molded, routed or otherwise formed  
17 therein. The planar section 868 is preferably colored to  
18 provide suitable contrast with the liquid solution  
19 flowing therethrough. A transparent flat plastic cover  
20 is positioned over the winding channel of the planar  
21 section 865 to form the closed channel of the capillary  
22 section. The fluid channel in the capillary section  
23 preferably has an I.D. of approximately 2 mm. The second  
24 inlet port 864 provides an additional means to add  
25 medication to the nebulizing catheter liquid flow. When  
26 the capillary channel in the section 852 has been filled,  
27 the gas is used to pressurize the tube and force the  
28 fluid to the catheter tip. The second filter 864 acts as  
29 a restrictive orifice to precisely meter the flow to the  
30 nebulizing catheter. The clear capillary channel allows  
31 easy visualization of the drug flow by watching the gas-  
32 drug meniscus travel down the tube. The narrow tube  
33 makes the flow appear to move quickly even at slow  
34 delivery rates. Thus, any flow interruption can be  
35 easily observed. The capillary tubing section also  
36 ensures that almost 100% of the drug is delivered to the

1       catheter tip since there is no dead space in the line  
2       except at the injection port 860.

3           During ventilation of a patient with an  
4       endotracheal tube, especially when intubation that takes  
5       place for a long period of time, it is considered  
6       desirable to humidify the air being delivered. When a  
7       nebulization catheter is used for delivery of medicine,  
8       either in conjunction with an endotracheal tube or even  
9       without an endotracheal tube, it is possible to utilize  
10      the nebulization catheter for providing humidification in  
11      addition to medicine delivery. An embodiment of a flow  
12      delivery system for a nebulizing catheter incorporating  
13      humidification is shown in FIG. 53. A suitably large  
14      reservoir 866 holds sterile water or saline. The  
15      reservoir 866 is connected to the liquid supply lumen 867  
16      of a nebulization catheter 868. Solution is drawn into  
17      the nebulization catheter 868 from the reservoir 866 by  
18      negative pressure at the catheter tip, gravity, a pump in  
19      the solution supply line distal of the reservoir, or by  
20      pressurizing the reservoir by a suitable means.

21           Medicine may be added to the humidification  
22      water in at the following ways. In a first alternative,  
23      the medicine is added to the isotonic saline in the  
24      solution reservoir 866 thereby providing for high  
25      dilution and slow, continuous delivery of the medicine  
26      along with the water. In second alternative, the  
27      medicine is introduced into the solution supply line 867  
28      via an injection port 869 between the reservoir 866 and  
29      the liquid lumen of the catheter 868. The medicine may  
30      be delivered to the injection port of the solution supply  
31      line from a solution reservoir system such as system 800  
32      of FIG. 50. Using this latter alternative, a more  
33      concentrated dose of the medicine can be delivered at the  
34      specific time preferred by the physician. It may also be  
35      preferable to include a molecular sieve, check valve or  
36      air trap 870 between the reservoir 866 and the injection

1 port to the to ensure that the medicine cannot flow or  
2 diffuse backwards into the reservoir 866.

3 When delivering medicine to the lungs or when  
4 delivering water for humidification, it may be desired to  
5 heat the liquid prior to delivery. This may especially  
6 be appropriate since expanding gases which are associated  
7 with the nebulization of liquids may remove heat from the  
8 body. In order to address this concern, a heating  
9 element 871 may be associated with the liquid supply line  
10 867 to the nebulizing catheter 868. This heating element  
11 871 may include an electric coil wound around the supply  
12 line 867 or may use a heated water flow in a tubing wound  
13 around the supply line 867. The heating element 871 may  
14 be used in embodiments that provide for humidification as  
15 well as those that do not. Alternatively, the heating  
16 element 871 may be associated with the gas supply line or  
17 with the liquid reservoir 866,

18 It is generally considered preferable to  
19 operate the nebulizing catheter so as to generate an  
20 aerosol that is carried by a patient's inhalation to the  
21 lungs. This requires a pulsing of the aerosol generation  
22 so that it is timed to coincide with the inhalation of  
23 the patient. If the patient is intubated, the timing of  
24 the nebulization can be synchronized with the operation  
25 of the ventilator. It is recognized that it may be  
26 preferable to begin the nebulization slightly in advance  
27 of, at, or slightly after, the beginning of the  
28 inhalation period in order to account for the distance  
29 between the nebulization tip and the alveoli. Also, it  
30 may be preferable to stop the nebulization slightly  
31 before the end of the inhalation period in order to avoid  
32 wasting aerosol after the inhalation flow has stopped.

33 This continuous pulsing of the aerosol can be  
34 accomplished by a system 872 as shown in FIGS. 54 and 55.  
35 FIGS. 54 and 55 show a portion of the flow control system  
36 for a nebulizing catheter. A flow line 876 has an inlet  
37 880 and an outlet 884. The flow line 876 may be formed

1 of a soft (e.g. compliant) tube. The inlet 880 connects  
2 to the source of liquid medicine and in particular may  
3 attach to the liquid outlet (828 or 856) of the liquid  
4 reservoirs shown in FIGS. 50 - 52. The flow line outlet  
5 884 in FIGS. 54 and 55 connects to the liquid inlet port  
6 on the manifold of the nebulizing catheter, such as port  
7 32 in FIGS. 1 and 2. Located around a portion of the  
8 flow line 876 is an actuator piston 888. The actuator  
9 piston 888 includes a solenoid pinch valve 892 that can  
10 impinge upon the portion of the liquid flow line 876  
11 therethrough thereby pinching it off. The  
12 actuator piston 888 is connected to and operated by a  
13 controller that receives input from the ventilator (such  
14 as from the auxiliary port used for an external  
15 nebulizer) so that the actuator piston 888 is operated to  
16 open and close the flow line synchronous with the  
17 inhalation and exhalation phases of the ventilator.  
18 Instead of a solenoid piston, a metering valve or  
19 reversible syringe pump may be used.

20 In a preferred embodiment, the flow control  
21 system 872 uses a dual solenoid arrangement to provide a  
22 draw-back feature. Pulsing of the liquid flow by  
23 actuation of the actuator piston 888 may result in some  
24 liquid being left at the distal nebulizer liquid orifice  
25 when the pressure is turned off. This may result in  
26 small amounts of liquid drooling from the distal liquid  
27 orifice tip since the liquid is not being expelled under  
28 controlled pressure conditions. In order to limit the  
29 occurrence of such drooling, a draw back feature is  
30 provided in the flow control system. The draw back  
31 feature is provided by a second solenoid 896 which is  
32 associated with a bladder 900 that communicates with the  
33 flow line 876. The bladder 900 communicates with the  
34 flow control line 876 downstream of the actuator piston  
35 888. A small amount of fluid (liquid/air) occupies the  
36 bladder 900. The bladder is composed of an elastic  
37 material that is formed with a tendency to recover to an

1 expanded size. When the actuator piston 888 opens to  
2 allow the flow of fluid to the distal end of the  
3 nebulizing catheter, the second solenoid 896 moves to a  
4 closed position thereby compressing the bladder 900 and  
5 squeezing fluid out of it into the fluid flow line 876,  
6 as shown in FIG. 54. During the exhalation stage of the  
7 ventilation cycle, the actuator piston 888 closes to shut  
8 off the flow of fluid to the distal end of the nebulizing  
9 catheter. When the actuator piston 888 closes, the  
10 second solenoid 896 opens, as shown in FIG. 55. This  
11 allows the bladder 900 to resiliently recover to its  
12 expanded size, and when it does, it draws fluid into it  
13 from the fluid flow line 876. Because the fluid flow  
14 line 876 is closed proximally at the actuator piston 888,  
15 when the bladder draws fluid into it from the fluid flow  
16 line 876, it draws fluid from the distal end of the fluid  
17 flow line that connects to the nebulizing catheter liquid  
18 lumen. This causes the entire column of liquid in the  
19 liquid lumen of the nebulizing catheter to move slightly  
20 in a reverse direction (i.e. proximally) thereby moving  
21 the liquid away from the distal orifice. In this manner,  
22 the flow control system of FIGS. 54 and 55 allows the  
23 draw back of liquid in the flow line in a reverse  
24 direction during the exhalation phase of the ventilator  
25 when the liquid flow line is shut off.

26 **VII. Selective Nebulization Therapy Delivery**

27 When delivering medication with a nebulizing  
28 catheter, it may be desirable to deliver the medication  
29 to only one of the bronchi of the lungs and not the other  
30 or to only certain bronchia and not others. A reason for  
31 this type of selective therapy may be that only one area  
32 of the lungs requires medication. An embodiment of the  
33 invention shown in FIG. 56 facilitates selective delivery  
34 of a medication via a nebulizing catheter to only one  
35 bronchus. In FIG. 56, an endotracheal tube 904 is  
36 positioned in a trachea 908 of a patient. A nebulizing

1       catheter 912 is positioned in the endotracheal tube 904.  
2       This nebulizing catheter 904 may be similar to the  
3       embodiments described above. This nebulizing catheter  
4       904 may even be of the type that is non-removably  
5       incorporated into the endotracheal tube. A second  
6       catheter 916 extends distally of the endotracheal tube  
7       904. The second catheter 916 may be positioned in the  
8       ventilation lumen 920 of the endotracheal tube 904. The  
9       second catheter 916 includes a lumen through which a low  
10      flow pressurized gas can be conveyed. A proximal end of  
11      the second catheter 916 extends out of the proximal end  
12      of the endotracheal tube 904 through a suitable fitting,  
13      such as the fitting described in U.S. Pat. No. 5,078,131  
14      (Foley). A suitable source of pressurized gas is  
15      attached to a proximal end of the second catheter 916.  
16      This gas source may be the same gas source used for the  
17      pressurized gas lumen of the nebulization catheter 912.  
18      A distal end 928 of the second catheter 916 is positioned  
19      in the bronchus 932 other than the bronchus to which it  
20      is desired to deliver nebulized medication. Pressurized  
21      gas is delivered through the second catheter 916 out an  
22      orifice 936 in the distal end thereof. The delivery of  
23      pressurized gas out the distal end 936 of the second  
24      catheter 916 causes the pressure level in the bronchus  
25      932 to be slightly greater than in the other bronchus.  
26      Accordingly, when the nebulizing catheter 912 generates  
27      an aerosol of liquid medicine, it will tend to flow with  
28      the inhalation stream from the endotracheal tube 904 to  
29      the bronchus other than the one with the second catheter  
30      916. In this manner, one of the bronchi of the lungs, or  
31      even selected bronchia, can be selectively medicated  
32      using a single nebulization catheter positioned in the  
33      endotracheal tube.

34       VIII.      Timing of Nebulization

35       As mentioned before, in order to deliver the  
36       nebulized medicine to the lungs, it is preferred that the

1       medicine is carried by the inhalation of the patient. A  
2       number of factors affect the efficiency of the medicine  
3       delivered this way. The following embodiments are  
4       directed to improving drug delivery efficiency taking  
5       into account some of these factors.

6       If the patient is intubated, it may be possible  
7       to synchronize the timing of the nebulization pulse with  
8       the patient's ventilation. In one embodiment, this may  
9       be accomplished by providing an interface between the  
10      ventilator and the nebulizer. In some circumstances it  
11      may be preferred to provide other means for triggering  
12      the nebulization. For example, the ventilator being used  
13      may not provide a suitable interface. Also, the  
14      ventilator may not provide sufficiently accurate  
15      information concerning the patient's respiration to  
16      enable the nebulization catheter to operate with highest  
17      efficiency. In such situations, it may be preferred to  
18      utilize one or more separate sensors to obtain  
19      information that can be used to trigger and operate the  
20      nebulization catheter.

21      Referring to FIG. 57, there is a nebulizing  
22      catheter 944 positioned in an endotracheal tube 948  
23      located in the trachea 952 of a patient. A proximal end  
24      of the endotracheal tube 948 is connected to a ventilator  
25      956. In order to obtain physiological information  
26      concerning the patient's respiration for use in timing  
27      the generation of nebulization pulses by the nebulization  
28      catheter 944, one or more sensors may be used. For  
29      example, a first sensor 960 may be located on a distal  
30      end of the endotracheal tube 948. In addition, a sensor  
31      964 may be positioned on the nebulization catheter 944.  
32      Another sensor 968 may be positioned on a separate  
33      device, such as a separate catheter 972 which is located  
34      further distally in the respiratory system. In addition,  
35      a sensor 976 may be positioned in the ventilator circuit  
36      of the ventilator 956 or in a ventilator auxiliary port,  
37      if available, or elsewhere on the patient. These sensors

1 960, 964, 968, and 976 may be types of sensors that  
2 measure pressure, flow or a physiological parameter of  
3 the patient, such as muscle contraction,  
4 electrophysiological activity, etc. In alternative  
5 embodiments, one or more of these sensors may be used.

6 FIGS. 58 and 59 show alternative embodiments of  
7 nebulization catheters that incorporate sensors. In FIG.  
8 58, a nebulization catheter 980 is shown. This  
9 nebulization catheter 980 may be similar to the  
10 nebulization catheter in FIG. 11. In FIG. 58, a main  
11 shaft 984 includes a plurality of lumens with a centrally  
12 located lumen 988 used to deliver a liquid medicine and a  
13 plurality of lumens 992 located peripherally around it  
14 used to deliver a pressurized gas. One of the peripheral  
15 lumens 996 is not used for pressurized gas delivery, but  
16 instead is used for sensing purposes. This may be  
17 accomplished by forming an aperture 1000 through a wall  
18 of the main shaft 984. The aperture communicates with  
19 the sensing lumen 996. The aperture 1000 may be open or  
20 may be covered with a flexible diaphragm that permits  
21 transmission of pressure across it. A pressure sensing  
22 device may be located at a proximal end of the nebulizing  
23 catheter. The pressure at the distal end of the  
24 nebulizing catheter can be sensed by the proximally  
25 located sensing device via the sensing lumen 996. This  
26 could rely on pneumatic sensing of the distal air  
27 pressure. Because of the effect of the distal gas  
28 pressurization orifice, pressure sensing through the  
29 sensing lumen 996 may be used for purposes of gross  
30 overpressure for safety purposes. Alternatively, the  
31 pressure sensing lumen 996 may be used during periods of  
32 time when a pressurizing gas is not being delivered to  
33 sense the patient's physiological airway pressure.

34 FIG. 59 shows another embodiment of a pressure  
35 sensing nebulization catheter. This embodiment is  
36 similar to the embodiment of FIG. 58 except that a sensor  
37 1004 is located at a distal end of the catheter 980,

1 specifically in the aperture 1000. In this embodiment,  
2 the sensor 1004 is a pressure transducer. Wire leads  
3 1008 extend proximally from the sensor 1004 via the lumen  
4 996. Instead of measuring pressure, the sensor 1004  
5 could measure the flow at the distal end of the catheter.  
6 This may be accomplished by piezoelectric, optical, Hall  
7 effect, or other types of sensor technologies. The  
8 sensor may also be of a fiber optic type.

9 Although the embodiments of FIGS. 58 and 59  
10 show sensing apparatuses associated with a nebulization  
11 catheter, these same types of sensors could also be used  
12 in the endotracheal tube 948, the separate catheter 972,  
13 or the ventilator 956 of FIG. 57 or the ventilator  
14 circuit.

15 The sensor outputs information to a controller  
16 1012 that operates the flow control portion 1013 of the  
17 nebulization catheter system. The flow control portion  
18 may include the flow control assembly 872 (shown in FIG.  
19 55) as well as include the control functions for gas  
20 pressurization. The controller 1012 may have preset  
21 triggering parameters or may be user adjustable. The  
22 controller 1012 may use airway flow, pressure, or  
23 physiological activity as a basis for controlling the  
24 flow control assembly 1013. The controller 1012 may  
25 provide for pulsing based upon any one of the following  
26 modes: (1) a controlled volume (bolus) of medicine is  
27 delivered with each pulse; (2) medicine is delivered  
28 until a physiological condition is sensed, e.g.  
29 exhalation; or (3) medicine is delivered for a fixable  
30 time interval, e.g. 2 seconds. These modes of operation  
31 may be selectable by the physician based upon the  
32 preferred treatment taking into account the patient's  
33 condition, the type of medicine being delivered, etc.

34 It may also be desired to regulate the delivery  
35 of aerosol so that it is not delivered with every  
36 inhalation. As mentioned above, one concern with  
37 delivery of an expanding gas is the cooling effect that

1       it may have on the body. This can be a factor with high  
2       gas flow rates. Accordingly, it may be preferable to  
3       deliver aerosol on every other inhalation or every third  
4       inhalation, and so on. Alternatively, it may be  
5       preferred to deliver aerosol for certain periods of time,  
6       e.g. 5 minutes every hour. Therefore, by alternating  
7       aerosol delivery, the cooling effect associated with it  
8       can be reduced.

9       IX. Alternative Embodiments  
10      A. Nebulizing Catheter Incorporated in  
11       Endotracheal Tube

12       The various embodiments of nebulizing  
13       catheters, disclosed above, have been described as being  
14       either adapted for use in conjunction with a separate  
15       endotracheal tube, or adapted to be used without an  
16       endotracheal tube. If used with an endotracheal tube,  
17       the embodiments of the nebulizing catheter disclosed  
18       above are preferably removable from the endotracheal tube  
19       if one is present. It is noted that many of the  
20       embodiments of the present invention disclosed herein may  
21       also be used in conjunction with a nebulization catheter  
22       that is non-removable from an endotracheal tube, i.e. in  
23       which the nebulizing catheter is incorporated into and  
24       forms part of the endotracheal tube. An endotracheal  
25       tube that provides for nebulized medication delivery is  
26       described in a patent application filed by Dr. Neil R.  
27       MacIntyre on March 10, 1992 entitled "Endotracheal Tube  
28       Adapted for Aerosol Generation at Distal End Thereof",  
29       the entire disclosure of which is incorporated herein by  
30       reference. According to a system developed by Dr.  
31       MacIntyre, there is provided an endotracheal tube that  
32       provides for nebulization of a medication at a distal end  
33       thereof. According to Dr. MacIntyre's system, an  
34       endotracheal tube includes two additional, separate  
35       lumens, in addition to its main ventilation lumen used  
36       for the patient's breathing airflow. A medication in a

1 liquid form is conveyed through one of the additional  
2 lumens and a pressurized gas is conveyed through the  
3 other lumen. The two additional lumens have distal  
4 openings near the distal end of the endotracheal tube  
5 airflow lumen. The distal opening of the pressurized gas  
6 lumen directs the pressurized gas across the distal  
7 medication lumen opening thereby nebulizing the liquid  
8 medication so that it can be delivered to the patient's  
9 lungs. It is intended that the present invention covers  
10 embodiments of nebulization catheters that are non-  
11 removable relative to an endotracheal tube.

12       B. Aerosol Generation with Porous Material

13       FIG. 60 shows another catheter 1060 for  
14 producing an aerosol. The catheter 1060 generates an  
15 aerosol, or aerosol-like plume by use of a porous  
16 material or sponge located in a lumen of the catheter.  
17 The catheter 1060 has a main shaft 1064 with a lumen 1068  
18 through which liquid medicine is conveyed under pressure  
19 and a lumen 1072 through which a gas is conveyed under  
20 pressure. A porous material 1076 is located in a distal  
21 end of the shaft 1064 so that both lumens 1068 and 1072  
22 convey their contents into the porous material 1076. The  
23 porous material 1076 may be a porous polyethylene made by  
24 Porex. Alternatively, the porous material may be a  
25 polymer sponge or other polymer material. Located in the  
26 main shaft 1064 distal of the porous 1076 is an end cap  
27 1080 with an orifice 1084 located therein. The orifice  
28 is small and maintains a positive back pressure in the  
29 catheter shaft and porous material area. The end cap  
30 1080 is separated from the distal side of the porous  
31 material 1076 by a small gap 1082. The liquid and gas  
32 delivered under pressure to the porous material 1076  
33 migrate through the porous across the gap 1082 toward the  
34 aperture 1084. The liquid and gas become intermixed  
35 under pressure and as they are expelled from the fine tip  
36 orifice the gas expands and disperses the liquid

1 particles into fine droplets. Upon discharging through  
2 the aperture 1084, the medicine forms tiny droplets, e.g.  
3 an aerosol. The aerosol is conveyed to the lungs of the  
4 patient in a manner similar to that described in the  
5 embodiments above. An advantage of using a porous  
6 material or sponge at the distal liquid orifice is that  
7 it reduces drooling of the liquid.

8           C. Secondary Aerosol Generation

9           In some situations it may be desirable to  
10 modify the primary aerosol spray generated by a  
11 nebulization catheter. One way that this can be  
12 accomplished is by causing the primary aerosol spray to  
13 impact upon a baffle placed in its path, the velocity and  
14 direction of the spray can be altered and the size of the  
15 distribution of the aerosol can be modified creating a  
16 secondary aerosol. Impaction upon a properly located  
17 baffle can break up large aerosol particles creating a  
18 finer aerosol mist. The baffle also deflects or diffuses  
19 the airstream carrying the particles reducing their  
20 forward velocity and altering their direction. This can  
21 lessen impaction on the carina or airways and enhance the  
22 entrainment of the particles into the inspiratory flow.  
23 Embodiments of nebulizing catheters incorporating an  
24 impaction baffle to provide a secondary aerosol are shown  
25 in FIGS. 61-64.

26           Referring to FIG. 61, a nebulization catheter  
27 1140 has a gas lumen 1142 and a liquid lumen 1144 located  
28 in a shaft 1146 of the catheter. The gas lumen 1142  
29 conveys a pressurized gas to a distal gas orifice 1148  
30 and the liquid lumen 1144 conveys liquid to a distal  
31 liquid orifice 1150. A baffle 1152 connects to a baffle  
32 extension tube 1154 so that the baffle 1152 is located  
33 distally of the liquid orifice 1150. The baffle 1152 is  
34 preferably located as close to the solution orifice 1150  
35 as possible without interfering with the generation of  
36 the primary aerosol.

1           Some of the primary aerosol that is not broken  
2        into fine particles may remain on the baffle 1152 and  
3        build up over time forming a thin liquid film on the  
4        surface of the baffle 1152. If this film is left to  
5        build up, it will form droplets that either fall or are  
6        blown off the baffle. These droplets may become quite  
7        large and of little or no therapeutic value representing  
8        a waste of the solution.

9           In order to recirculate this film of solution,  
10       the baffle 1152 may be used to collect and return the  
11       liquid solution to a liquid supply lumen 1144 To achieve  
12       this, the baffle may have with one or more orifices 1158  
13       or porous material on its surface of the baffle 1152 for  
14       the collection of the film of solution. The orifices  
15       1158 drain into or through the baffle, and are in fluid  
16       communication with the solution supply lumen 1144 via a  
17       lumen located inside of the extension tube 1154. The  
18       lumen inside the extension tube 1154 may communicate  
19       directly with the solution lumen 1144 or extension  
20       thereof.

21           In the embodiment of FIG. 61, the negative  
22       pressure generated at the nebulization orifice 1150 by  
23       the gas flow over it is used to draw the recirculated  
24       solution from the baffle recirculation orifice 1158 via  
25       the lumen in the extension 1154 and out the liquid  
26       orifice 1150 again. In this case, the recirculation  
27       orifices 1158 or surface should be in an area of higher  
28       ambient pressure than the solution orifice 1150 to cause  
29       the recirculation of the fluid. This may be accomplished  
30       by locating the collection orifices 1158 on a distal side  
31       of the baffle 1152 opposite the solution and gas orifices  
32       1150 and 1148. The flow of new solution (from the  
33       proximally located solution reservoir) pumped into the  
34       solution lumen 1144 should be less than the flow drawn  
35       from the solution orifice 1150 to ensure that least some  
36       of the solution from the baffle 1152 is recirculated to  
37       the orifice 1150.

1 FIG. 62 shows another embodiment of a  
2 nebulization catheter that incorporates a baffle for the  
3 purpose of generating a secondary aerosol. This  
4 embodiment is similar to the nebulization catheter in  
5 FIG. 61 with the exception that the recirculated fluid is  
6 drawn back into a recirculation lumen 1160 in the  
7 catheter shaft 1146. The recirculation lumen 1160  
8 communicates with the liquid lumen 1144 at a junction  
9 1162 at which location the recirculated solution is mixed  
10 with newly supplied liquid in the solution lumen 1144.

11 FIG. 63 shows another alternative embodiment.  
12 This embodiment is similar to the embodiment of FIG. 62  
13 except that the recirculated solution is routed from the  
14 baffle 1152 to the recirculation lumen 1160 and then to a  
15 separate solution orifice for re-nebulization. This  
16 dedicated solution orifice 1161 is also located at the  
17 catheter tip near a gas orifice 1148 to produce  
18 nebulization. The aerosol generated from this separate  
19 orifice 1161 is directed into the common baffle 1158 to  
20 break it into smaller particles and a portion of the  
21 solution will again remain on the baffle and be  
22 recirculated. This approach can eliminate the  
23 difficulties of balancing the flow of new and  
24 recirculated solution to a single solution orifice.

25 Referring to FIG. 64, there is another  
26 embodiment of a nebulizing catheter incorporating a  
27 baffle for the generation of a secondary aerosol. In  
28 this embodiment, a nebulizing catheter 1170 has a shaft  
29 1172 with a liquid lumen 1174 connected to a liquid  
30 supply 1176. A gas lumen 1178 connects to a pressured  
31 gas source 1180. The liquid lumen 1174 communicates with  
32 a distal liquid orifice 1182 and the gas lumen  
33 communicates with a distal gas orifice 1184. A baffle  
34 1186 is located in front of the liquid orifice 1182.  
35 Aerosol impacting on the baffle 1186 produces a secondary  
36 aerosol that flows around the baffle 1186. A residue  
37 film of liquid migrates around the baffle 1186 and enters

1 into baffle orifices 1190 located on the distal side of  
2 the baffle 1186. The baffle orifices 1190 communicate  
3 with a recirculation lumen 1192 that extends through the  
4 catheter shaft to a reservoir 1194 located outside of the  
5 body where the recirculated solution is combined with  
6 non-recirculated solution pumped from a proximal drug  
7 reservoir. The flow of recirculated and non-recirculated  
8 solution into the system should be carefully balanced to  
9 match the amount of aerosol generated. To achieve this,  
10 flow metering and pumping strategies can be employed.

11           D. Nebulization Catheter with  
12           Pressurized Propellant-Drug Canister

13           In the embodiments described above, medicine is  
14 delivered in liquid form to the distal liquid orifice.  
15           In another embodiment, illustrated in the diagram of FIG.  
16 65, the medicine may be mixed with a propellant and  
17 maintained under pressure and delivered under pressure to  
18 the distal tip of a nebulizing catheter 1198. A  
19 pressured medicine-liquid propellant mixture could be  
20 supplied from a pressurized canister 1200 such as those  
21 used as a component of a metered or non-metered dose  
22 inhaler. By using a propellant, an aerosol could be  
23 generated from the distal end 1202 of the catheter even  
24 without the addition of the pressurized nebulizing gas.  
25 However, the delivery of pressurized gas 1204 from the  
26 distal end of the nebulization catheter would be used to  
27 assist in breaking up any larger medicine particles and  
28 also assist dispersing the aerosolized drug solution  
29 delivered through the catheter as well as help shape the  
30 aerosol plume. For example, the delivery of the  
31 pressurized, nebulizing gas may assist in shielding the  
32 aerosol generated by the medicine-liquid propellant  
33 mixture and help avoid losses due to impaction.

34           E. Nebulizing Function Incorporated in  
35           Suction Catheter

1           As mentioned above, the nebulizing catheter can  
2    be incorporated into another device, such as an  
3    endotracheal tube, either removably or non-removably.  
4    Another such device into which a nebulizing catheter can  
5    be adapted is a suction or aspiration catheter. A  
6    suction catheter is sometimes used in conjunction with  
7    patients who are intubated. A suction catheter has an  
8    O.D. and a length such that it can be inserted through  
9    the ventilation lumen of an endotracheal tube. The  
10   suction catheter is used to aspirate fluids and mucin  
11   secretions that collect in the respiratory tract of in  
12   the endotracheal tube of a patient who is intubated. A  
13   conventional suction catheter is inserted down the  
14   ventilation lumen of the endotracheal tube and out the  
15   distal end. A mucolytic agent may be instilled as a  
16   liquid via a lumen of the suction catheter to help in the  
17   withdrawal of mucin from the trachea or bronchi. The  
18   suction catheter may then be withdrawn from the  
19   endotracheal tube and either disposed or retained in a  
20   sterile sheath connected to a proximal end of the  
21   endotracheal tube so that it can be reinserted into the  
22   endotracheal tube again.

23           A nebulizing catheter can be incorporated into  
24    a suction catheter so that a single device can perform  
25    both the functions of aspiration and nebulization for  
26    aerosol delivery. In an alternative embodiment of the  
27    present invention, the nebulizing catheter, such as  
28    described above, could be incorporated into a suction  
29    catheter so that a single catheter can provide both  
30    functions. This could be accomplished by provided any of  
31    the embodiments of the nebulization catheter described  
32    above with a separate lumen for the purpose of providing  
33    a suction to withdraw fluid from a patient's respiratory  
34    tract. Combining the functions of a suction catheter and  
35    nebulization catheter into a single device has the  
36    advantages of avoiding the expense of separate products

1 as well as avoiding the inconvenience of inserting and  
2 withdrawing separate devices.

3 Embodiments of a suction catheter combined with  
4 a nebulization catheter are shown catheter is FIGS. 66-  
5 73. FIGS. 66-70 show a suction catheter assembly 1220.  
6 The suction catheter assembly 1220 includes a suction  
7 catheter shaft 1222 slidably located inside of a flexible  
8 sheath 1224. A suction lumen 1225 extends through the  
9 suction catheter shaft 1222. A proximal manifold 1226  
10 includes a port 1228 for connecting a vacuum source to  
11 the suction catheter lumen 1225. A valve 1230 operates  
12 to open and close the port 1228. A distal sleeve 1232  
13 provides for connecting to an endotracheal tube such that  
14 the suction catheter shaft 1222 can be inserted into the  
15 endotracheal tube by pushing the proximal manifold 1226  
16 toward the distal sleeve 1232. The distal sleeve 1232  
17 may include a manifold for connection to a flush port  
18 1233. A seal 1235 located in the sleeve 1232 closely  
19 bears on the suction catheter shaft to remove mucous or  
20 other unwanted materials that can be removed via the  
21 flush port 1233. The shaft of the suction catheter may  
22 be provided with a low friction, e.g. hydrophilic,  
23 coating to reduce adhesion of mucous.

24 The suction catheter assembly 1220 includes two  
25 additional lumens 1234 and 1236. These lumens 1234 and  
26 1236 are located in a wall of the suction catheter shaft  
27 1222. These lumens 1234 and 1236 communicate with distal  
28 orifices 1238 and 1240 located at a distal end of the  
29 suction catheter shaft 1222. These lumens 1234 and 1236  
30 are used to deliver a liquid medicine and a pressurized  
31 gas for nebulizing the liquid medicine, as described  
32 above. Also located at a distal end of the suction  
33 catheter shaft 1222 are suction openings 1242.

34 The suction catheter assembly 1220 can be used  
35 in a conventional manner to remove mucin from the trachea  
36 and from the bronchi. The suction catheter assembly 1220  
37 can also be used to deliver medicines to the lungs as an

1 aerosol by means of the nebulizing lumens 1234 and 1236.  
2 The nebulizing lumens can also be used to deliver  
3 mucolytic agents as an aerosol. Because the fine aerosol  
4 delivered by the nebulizing lumens can be carried by a  
5 patient's inspiratory airflow into the bronchi, the  
6 mucolytic agent can be delivered further into bronchi  
7 compared to a suction catheter that merely instills or  
8 generates a coarse spray of a mucolytic agent. In  
9 addition, the flow velocity produced by the gas  
10 pressurization lumen may be used to assist in breaking up  
11 mucous at the end of the suction catheter.

12 When using the suction catheter assembly 1220,  
13 it can be positioned so that a distal end of the suction  
14 catheter shaft 1222 is close to the distal end of the  
15 endotracheal tube 1250 as shown in FIG. 68 or  
16 alternatively the suction catheter shaft 1222 can be  
17 positioned so that it extends past the distal end of the  
18 endotracheal tube 1250 as shown in FIG. 70. As shown in  
19 FIG. 70, the suction catheter shaft 1220 may be formed  
20 with a distal curvature so that the distal end can be  
21 brought into proximity with the tracheal wall.

22 Rather than incorporate the nebulizing lumens  
23 into the wall of the suction catheter, it may be  
24 preferably in many situations to use a conventional  
25 suction catheter with a stand-alone nebulizing catheter.  
26 The stand-alone nebulizing catheter may be similar to any  
27 of the embodiments described above. A suction catheter  
28 and a nebulizing catheter can readily be used together  
29 with the alternative versions of the manifolds shown in  
30 FIGS. 71-73.

31 Referring to FIG. 71, an endotracheal tube 1252  
32 has a proximal end with a single port 1254. A suction  
33 catheter 1256 has a distal manifold 1258. The distal  
34 manifold 1256 could be formed as part of the suction  
35 catheter 1256 or could be provided as a separate  
36 component. The suction catheter manifold 1258 connects  
37 to the single port 1254 of the endotracheal tube 1252.

1 The manifold 1258 has a first port 1260 for connecting to  
2 a ventilator and a second port 1264 for connecting to a  
3 proximal end of a nebulizing catheter 1266. As shown in  
4 FIG. 71, the nebulizing catheter 1266 includes a sterile  
5 sheath 1268 which is similar to the sheath included on  
6 the suction catheter 1262. In the embodiment of FIG. 71,  
7 the suction catheter 1256 and the nebulizing catheter  
8 1266 are positioned alternately inside the ventilation  
9 lumen of the endotracheal tube 1252. The suction  
10 catheter or the nebulizing catheter can be withdrawn  
11 temporarily and maintained in its sterile sheath while  
12 the other is being used.

13 Referring to FIG. 72 there is another  
14 arrangement for connecting a suction catheter and  
15 nebulizing catheter to an endotracheal tube. In this  
16 embodiment, a manifold 1270 connects to the proximal end  
17 of the endotracheal tube 1252. The manifold 1270 has  
18 port 1274 for receiving the nebulizing catheter 1266 and  
19 a second port 1276. A distal manifold 1278 of a suction  
20 catheter 1280 connects to the second port 1276. The  
21 suction catheter manifold 1278 has a port 1282 for  
22 connecting to the ventilator. This arrangement can be  
23 used similarly to the arrangement of FIG. 71.

24 FIG. 73 shows still another arrangement for  
25 connecting a suction catheter and a nebulizing catheter  
26 to an endotracheal tube. In this embodiment, the  
27 endotracheal tube 1252 is provided with a proximal end  
28 that includes dual ports. A first port 1284 receives the  
29 nebulizing catheter 1266. The second port 1286 may be  
30 connected to either directly to a ventilator or may be  
31 connected to a distal end of a suction catheter (not  
32 shown) in a conventional manner.

33 In another alternative embodiment (not shown),  
34 the nebulizing catheter could be positioned down the  
35 suction lumen of the suction catheter.

36 FIG. 74 shows another embodiment of a suction  
37 catheter also incorporating a nebulization of an aerosol.

1 In FIG. 74, a suction catheter 1400 is extends from the  
2 ventilation lumen of an endotracheal tube 1250. The  
3 suction catheter 1400 includes distal suction orifices  
4 1402 located close to the distal end of the suction  
5 catheter shaft. Located along the suction catheter shaft  
6 proximally of the suction orifices 1402 are one or more  
7 pairs of liquid and gas orifices 1404. The liquid and  
8 gas orifice pairs 1404 are located with respect to each  
9 other to produce an aerosol of the liquid being delivered  
10 to the liquid orifice as in the previous embodiments.  
11 The nebulization orifices 1404 are oriented radially from  
12 the suction catheter shaft to direct the aerosol  
13 delivered from the nebulization orifices 1404 toward the  
14 airway passage wall. In one embodiment, the aerosol  
15 being delivered is a mucolytic agent. The suction  
16 provided by the suction orifices draws the mucolytic  
17 agent delivered from the nebulization orifices as well as  
18 mucous treated by the mucolytic agent in a distal  
19 direction into the suction orifices 1402.

20 Another embodiment of the suction catheter with  
21 aerosol delivery is shown in FIG. 75. A suction catheter  
22 1410 is located in a ventilation lumen of the  
23 endotracheal tube 1250. As in the previous embodiment,  
24 the suction catheter 1410 has a distal suction orifice  
25 1412 for removing mucous from the airway passage. In  
26 addition, the suction catheter 1410 also includes distal  
27 gas and liquid orifices 1414 located in proximity to each  
28 other to produce a aerosol. The liquid and gas orifices  
29 are located in a distal extension 1416 of the suction  
30 catheter shaft so that they are distal of the suction  
31 orifice 1412. The liquid and gas nebulization orifices  
32 1414 are oriented in a proximal direction toward the  
33 suction orifice 1412. The distal extension 1416 is  
34 formed to bring the nebulization orifices 1414 close to  
35 the wall of airway passage so that the aerosol delivered  
36 from the nebulization orifices 1414 washes the airway  
37 passage wall. As in the previous embodiment, the aerosol

1 delivered may be a mucolytic agent to facilitate  
2 suctioning of the mucous out of the airway passage. The  
3 pressurized gas flow may be used to contribute to the  
4 dislodgement of mucous from the airway passage walls.

5       F. Nebulization with Vibration

6       A vibrating orifice, a screen with multiple  
7 orifices or perforations, or a vibrating wire located at  
8 the distal tip of the nebulizing catheter may also be  
9 employed to assist in the generation of fine aerosol  
10 particles. The vibration may be generated by  
11 electromechanical, hydraulic, pneumatic, or piezoelectric  
12 means. The vibrations may be generated at the tip of the  
13 catheter, in the shaft, or extracorporeally.

14       One embodiment of a nebulizing catheter  
15 incorporating a vibrating tip is shown in FIG. 76. A  
16 nebulizing catheter 1300 includes a shaft 1302 through  
17 which extend a lumen 1304 for the delivery of a liquid  
18 medicine and a lumen 1306 for the delivery of a  
19 pressurized gas. The liquid lumen 1304 communicates with  
20 a distal liquid orifice 1308 and the gas lumen 1306  
21 communicates with a distal gas orifice 1310 located at a  
22 distal end of the nebulizing catheter shaft. At the tip  
23 the orifices 1308 and 1310 may be drilled or formed in a  
24 piezoelectric material 1314 or may be drilled or formed  
25 in an orifice insert, plate, tube or screen mechanically  
26 attached to the tip such that the vibrations of the  
27 material are transferred to orifices. Although both the  
28 gas and liquid orifices may be vibrated, alternatively  
29 only the liquid orifice may be vibrated. In still a  
30 further embodiment, the entire shaft of the catheter may  
31 be vibrated so that the vibrations are transferred to the  
32 tip. The vibrations may be amplified by mechanical means  
33 to increase the amplitude of the orifice oscillation.  
34 Two electrical lead wires 1316 and 1318 may be used to  
35 conduct bipolar or unipolar pulses from an extracorporeal  
36 generator and control circuit to the piezoelectric

1 material 1314. The amplitude and frequency of the  
2 orifice vibrations may be adjusted to optimize aerosol  
3 production based on the gas and solution flow rates, the  
4 orifice configuration, and the desired size of the  
5 aerosol particles. The generation device would be  
6 provided with a current leakage sensor to terminate its  
7 operation in the event it detects current leakage in the  
8 system. The vibrations can be pulsed to coincide with  
9 inspiration and also to control heat generated by  
10 vibration at the tip. One or more gas supply lumens and  
11 orifices at the catheter tip can be used to assist in the  
12 dispersion and transport of the particles produced at the  
13 vibrating orifice.

14 In a further alternative embodiment, the  
15 orifice may be vibrated by means of a vibrating wire  
16 connected to the orifice that is caused to vibrate from a  
17 generator connected to the proximal end. In still a  
18 further embodiment, a vibrating wire, similar to the wire  
19 tip shown in FIGS. 16-19, may extend distally past a non-  
20 vibrating orifice to cause aerosolization of a liquid  
21 delivered from the orifice that impinges onto the  
22 vibrating wire. In a still further embodiment, the tip  
23 may be vibrated remotely, e.g. from a source outside the  
24 body, by means of a magnetic field.

25 A liquid supply to the catheter tip can also be  
26 rapidly pulsed to cause small droplets to be ejected at  
27 the solution orifice. This may cause a finer aerosol to  
28 be developed than by feeding a continuous stream of  
29 solution to the orifice. The pulsation can be  
30 accomplished by rapidly expanding and contracting all or  
31 part of the solution reservoir (including the lumen).  
32 The expansion and contraction of the reservoir can be  
33 caused by electromechanical, hydraulic, pneumatic, or  
34 piezoelectric actuators forming the reservoir, within the  
35 reservoir or moving flexible portions of the reservoir.  
36 Such an embodiment is shown in FIG. 76. A nebulizing  
37 catheter 1500 includes a shaft 1502 having a gas lumen

1 1502 connected to a source of pressurized gas 1504 and a  
2 liquid medicine lumen 1506 connected to a source of  
3 liquid medicine 1508. Included in the liquid medicine  
4 source 1508 is a means for imparting compression waves or  
5 pulsation into the liquid. The waves are indicated in  
6 the liquid at 1509. The wave imparting means may be a  
7 transducer 1510 or other similar device. The vibration  
8 inducing device 1510 may be driven by a frequency  
9 generator 1513 at a frequency greater than 100 hertz.  
10 The vibrations induced in the liquid may be focussed or  
11 directed toward the distal liquid orifice 1514.

12 In the case where the vibrations are generated  
13 at a location proximal of the tip, the nebulizing  
14 catheter shaft may incorporate a mechanical means in the  
15 shaft or near the orifices capable of transmitting or  
16 amplifying the pulsations. In the embodiment of FIG. 77,  
17 a wire 1516 may extend from the pulsation generating  
18 means 1510 into the liquid lumen 1506 to help convey the  
19 vibrations 1509 to the distal orifice 1514. The  
20 pulsations imparted to the liquid may be used to generate  
21 an aerosol from the distal liquid orifice 1514 or  
22 alternatively may be used in conjunction with the  
23 pressurized gas delivered through the gas lumen 1502 for  
24 enhanced aerosolization. The amplitude and frequency of  
25 the orifice vibrations may be adjusted to optimize  
26 aerosol production based on the gas and solution flow  
27 rates, the orifice configuration, and the desired size of  
28 the aerosol particles.

29 The volume dispersed from the liquid orifice  
30 1514 by each pulse should be less than approximately 10  
31 microliters and the pulsation should occur at a frequency  
32 greater than 100 Hertz, although smaller volumes and  
33 faster frequencies may be used to produce a finer  
34 aerosol. It is preferable that the reservoir and lumens  
35 be constructed of a material of minimal compliance to  
36 ensure minimal attenuation of the pulsation. The gas  
37 supply orifice at the catheter tip can be used to assist

1       in the dispersion and transport of the particles produced  
2       at the solution orifice. These micro pulsations can be  
3       incorporated into a series with pauses between them to  
4       coincide with the patient's inspiratory phase.

5            G. Other Method for Aerosol Generation

6       The above embodiments describe a nebulization  
7       catheter in which an aerosol is generated by directing a  
8       pressurized gas through a catheter near an orifice from  
9       which the liquid to be nebulized exits. It is considered  
10      to be within the scope of the invention described herein  
11      to use other means or agents to generate an aerosol for  
12      delivery of a medication to the respiratory tract. For  
13      example, the above embodiments may be used in conjunction  
14      with devices that utilize other means to generate an  
15      aerosol of a liquid medication. A liquid delivered by a  
16      single liquid lumen may be nebulized by applying  
17      ultrasonic energy to the liquid, electrospray, steam, or  
18      a micropump similar to those used in ink jet type  
19      printers. These alternative approaches to nebulization  
20      may be substituted for the use of a pressurized gas for  
21      some of the embodiments described above, or may be  
22      combined with pressurized gas or with each other to  
23      produce an aerosol of the liquid medication.

24       The nebulization catheter embodiments described  
25       herein could also be used in other types of nebulizers  
26       that are used externally of a patient's respiratory  
27       system, such as small volume nebulizers (SVN),  
28       humidification nebulizers, or nebulizers used for ocular  
29       or nasal drug administration. When used in such other  
30       types of nebulizers, the embodiments of the nebulization  
31       catheter disclosed herein provide for a fine aerosol  
32       without the potential disadvantages of impacting the  
33       liquid on a baffle or recirculating the liquid medicine  
34       on a continuous basis which are common in such  
35       nebulizers.

1           It is intended that the foregoing detailed  
2        description be regarded as illustrative rather than  
3        limiting and that it is understood that the following  
4        claims including all equivalents are intended to define  
5        the scope of the invention.